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AN EXPERIMENTAL INVESTIGATION OF AN UNDERWATER HIGH PRESSURE WA--ETC(U)
JAN 76 T J LABUS, J A HILARIS N61339-75-C-0025
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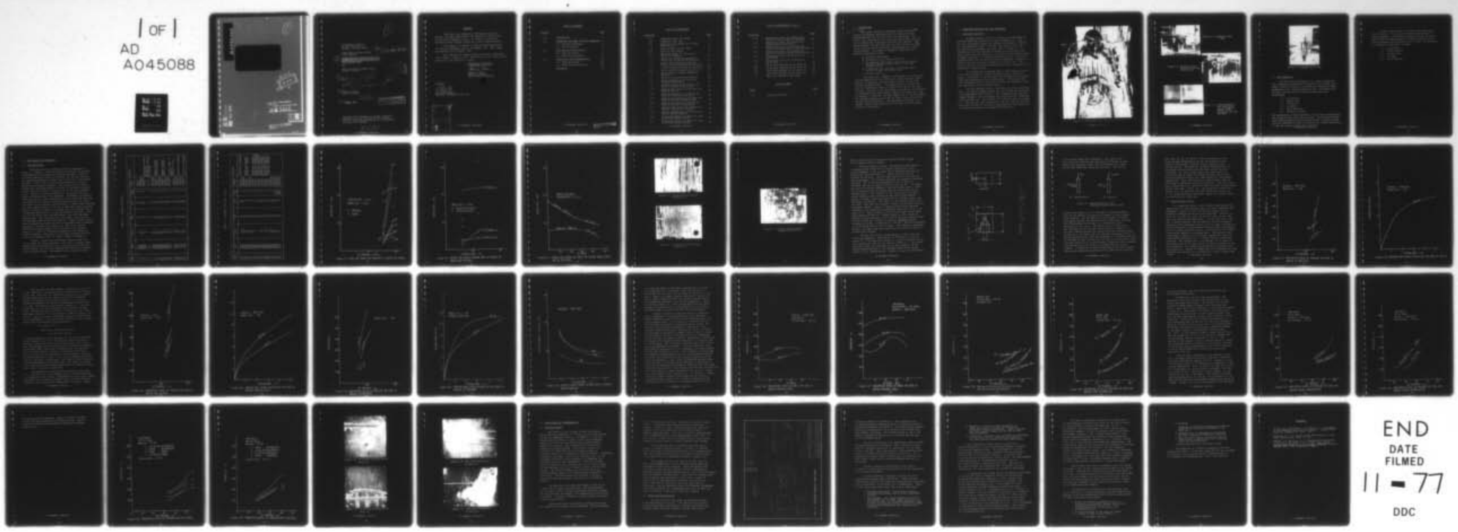

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(6) AN EXPERIMENTAL INVESTIGATION OF AN UNDERWATER HIGH PRESSURE WATER JET METAL CUTTING TOOL.

for

Naval Training Equipment Center
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by

(10) Thomas J. Labus
John A. Hilaris

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(11) January, 1976

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FOREWORD

This report was prepared by IIT Research Institute Chicago, Illinois under Contract No. N61339-75-C-0025 for the Naval Training Equipment Center. Mr. Robert E. Elliott of the Naval Coastal Systems Laboratory acted as program monitor.

This report is a summary of the work performed during the period 30 September 1974 to 31 December 1975. This report was submitted on 30 January, 1976.

The research was conducted under the direct supervision of Mr. Thomas J. Labus with Mr. John Hilaris and Mr. Frank Cyrnek assisting in the laboratory testing.

Respectfully submitted,
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1.0 INTRODUCTION

The recent workshop on Underwater Ship Husbandry ~~(1)~~ focused the problems associated with the need to develop improved methods and tools for diver use underwater. The topic of jet cleaning of hulls was discussed briefly, but data on its application, especially underwater was lacking. High pressure water jets have been used in a wide variety of applications and have shown significant advantageous over conventional methods. As related to underwater operations the possible advantages include:

- increased performance
- performance not a function of depth
- for cleaning application, the selective removal of marine fouling without damage to the anti-fouling coating
- a universal tool adaptable to different tasks by only a change in cutting head
- diver portable.

With these goals in mind, an experimental investigation of high pressure water jets for marine applications was undertaken by IIT Research Institute under contract to the Naval Training Equipment Center. The program centered around two aspects of underwater work 1) cutting metals and 2) ship hull cleaning. The goal of the program was to establish the pertinent jet parameters which controlled the process for each case, and to optimize, if possible, the more significant of these variables. The optimum parameters could then be used to size a system for the particular application. The experimental hardware, test methods, results and discussion are included in the following sections of the report.

2.0 LABORATORY EQUIPMENT AND TEST PARAMETERS

2.1 Laboratory Equipment

The high pressure water jet testing was accomplished on the main IITRI high pressure unit shown in Figure 2.1. This unit is a gas-backed intensifier capable of pressures to 200,000 psi and horsepower levels to 600 HP. The output of this unit was piped to an underwater test tank shown in Figure 2.2. A hydraulically driven platform was mounted in the bottom of the tank to hold the test specimens. A close-up of the driving system is shown in Figure 2.3. Traverse rates from 1/8 to 1/2 ips were generated while the specimen and jet were submerged. Figure 2.4 shows a view of the nozzle as mounted in the test tank. The cutting rate was varied by controlling the driving pressure of the pump using a bypass system.

Jet pressure was monitored using a quartz pressure transcucer (Kistler Model No. 119A02) mounted directly behind the nozzle. The output of the transducer was displayed on an oscilloscope and photographed using a scope camera. The pressure was then correlated with the penetration of the test specimen to produce penetration versus pressure curves.

For the cleaning studies a portable lance-type system was used. A 12,000 psi pumping system was used to pump an accumulator to the appropriate test pressure. The accumulator was then discharged through a lance containing the cleaning nozzle, producing a high pressure jet. The cleaning test system is shown in Figure 2.5. This unit was positioned next to the test tank and the hand held lance (visible in the center foreground) was then moved over the submerged specimen at the desired cleaning rate.

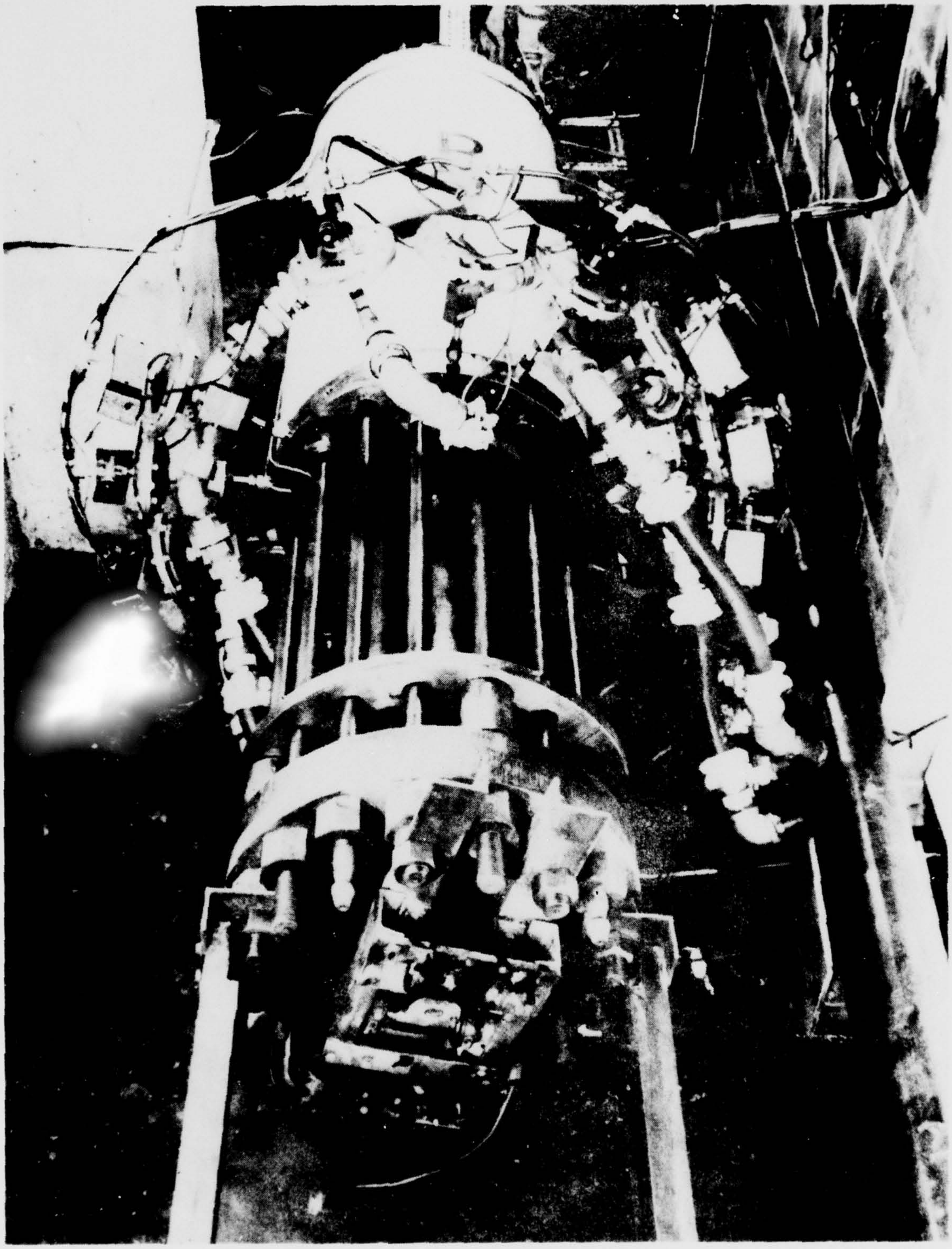

Figure 2.1 Laboratory Water Jet System

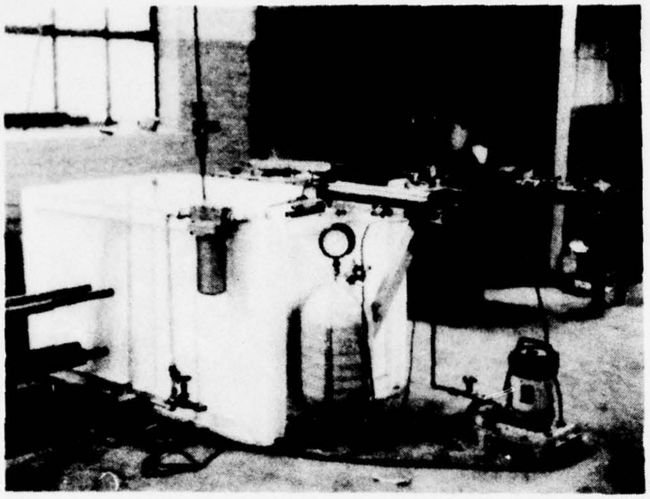

Figure 2.2 Underwater Test Tank

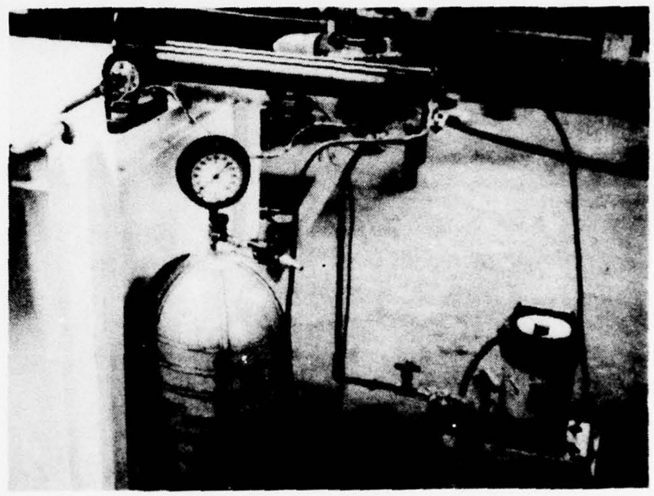

Figure 2.3 Hydraulic Drive System For Cutting Rate Control

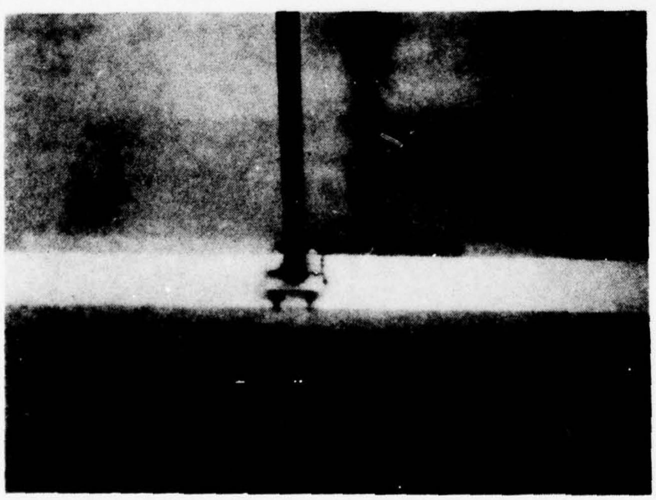

Figure 2.4 Nozzle Mounted In Test Tank (Dark Area To Right Of Nozzle Is The Surface Of The Test Specimen)

Figure 2.5 Cleaning Test System

2.2 Test Parameters

For both testing sequences (i.e., metal cutting and hull cleaning) the pertinent jet parameters were varied over a range of pratical interest to indicate the influence of these parameters on the cutting/cleaning process. Specifically for the metal cutting study the following parameters were investigated:

1.) jet pressure
2.) nozzle size
3.) cutting rate
4.) jet angle
5.) fluid additives
6.) abrasive injection

The optimization of these parameters for the metal cutting study was conducted using 1020 steel specimens. Using the best conditions obtained during the optimization study, a series of tests were also performed on HY80 to determine the cutting capabilities of the jet on high strength steel materials.

In the cleaning study, the testing was broken down into two groups: 1) testing on uncoated specimens and 2) coated specimens. The uncoated specimens were fouled steel plates without antifouling paint on their surfaces, and the coated specimens had antifouling paint on them. The pertinent jet parameters investigated included:

1.) jet pressure
2.) nozzle diameter
3.) cleaning rate
4.) jet angle
5.) nozzle geometry.

3.0 TEST RESULTS AND DISCUSSION

3.1 Cleaning Studies

The results of the cleaning studies are tabulated in Table 3.1. Figure 3.1 shows the weight loss versus jet pressure relationship for both coated and uncoated specimens. There is an extreme amount of scatter in the data, but the mass loss for the uncoated specimens is greater than in the case of the coated specimens. This is due to the larger accumulation of marine growth on the uncoated specimens. This weight loss is used to characterize the effectiveness of the jet in removing the marine growth, but can be used as criteria only if the coating remains intact. Figure 3.1 shows the effects of jet pressure and jet angle on the mass loss of the specimens. Increasing jet pressure increases mass loss while decreasing jet angle increases mass loss. Increasing the jet pressure should increase the mass loss since more power is being applied and decreasing jet angle should increase mass loss since the power of the jet is being more fully utilized. Figure 3.2 shows the effect of cleaning rate on the weight loss of the specimen under given jet angle and pressure conditions. Note that all the curves show increased weight loss with increasing cleaning rate. This indicates that the maximum utilization of the available power has not been achieved. Higher cleaning rates should increase the weight loss until an optimum value is achieved. Increases in cleaning rates beyond this point will produce ineffective material removal and an increase in the specific energy (i.e., ratio of horsepower expended per unit weight of material removed), Operating at the optimum cleaning rate also is the most efficient point in terms of energy consumption.

Figure 3.3 shows the relationship between weight loss and jet angle for coated specimens. Note that the larger nozzle diameter has less sensitivity to jet angle variations than the smaller nozzle, but that the horsepower requirements are greater than the smaller nozzle. The weight loss is greater for the

TABLE 3.1 CLEANING TEST DATA

Test No.	Jet Pressure psi.	Weight Loss grms.	Cleaning Rate ips.	Jet Angle deg.	Nozzle Dia. mm	Specimen Type	Comments
1	9500	3	6	15	.4	coated	
2	9500	4	6	15	.4	coated	
3	9500	82.5	6	15	.4	uncoated	
4	9500	17	6	15	.4	uncoated	
5	9500	7.5	6	15	.4	coated	Significant damage to coating
6	9500	4	6	15	.4	coated	Significant damage to coating
7	9500	51	6	15	.4	uncoated	
8	9500	21.5	6	15	.4	uncoated	
9	9500	13.5	12	15	.4	coated	Damaged coating
10	9000	12	12	15	.4	coated	Damaged coating
11	9500	64	12	15	.4	uncoated	
12	9500	26	12	15	.4	uncoated	
13	9500	10.5	12	30	.4	coated	Damaged coating
14	9500	7.5	12	30	.4	coated	Damaged coating
15	9500	55	12	30	.4	uncoated	
16	9500	82	12	30	.4	uncoated	
17	8250	8.5	12	30	.4	coated	Erratic damage to coating
18	8250	6.5	6	30	.4	coated	Damaged coating
19	8250	56.5	12	30	.4	uncoated	
20	8250	36	12	30	.4	uncoated	
21	7750	6	12	30	.4	coated	Undercoat undamaged
22	7750	41	12	30	.4	uncoated	
23	7750	35.5	12	30	.4	uncoated	
24	9500	22	12	45	.4	coated	Undercoat undamaged

TABLE 3.1 CLEANING TEST DATA (cont'd)

Test No.	Jet Pressure psi.	Weight Loss grms.	Cleaning Rate ips.	Jet Angle deg.	Nozzle Dia. mm	Specimen Type	Comments
25	7750	5	12	45	.4	coated	Undercoat undamaged
26	9500	111.5	12	45	.4	uncoated	
27	7750	17.5	12	45	.4	uncoated	
28	9500	18	12	0	.4	coated	Undercoat damaged
29	7750	8	12	0	.4	coated	Undercoat damaged
30	9500	103	12	0	.4	uncoated	
31	7750	12	12	0	.4	uncoated	
32	8250	19	12	0	.6	coated	Undercoat damaged
33	7000	7	12	0	.6	coated	Undercoat undamaged
34	7000	7	12	30	.6	coated	Undercoat undamaged
35	7000	4	12	45	.6	coated	Undercoat undamaged
36	7750	12	12	15	.4	coated	Undercoat damaged
37	7000	8	12	15	.4	coated	Undercoat damaged
38	5750	8	12	15	.4	coated	No fouling removed
39	9500	13.5	12	15	.4	coated	Undercoat damaged
40	7900	9	12	0	.4	coated	Undercoat damaged
41	6850	8.5	12	0	.4	coated	Undercoat damaged
42	8000	112.5	12	45	.4	uncoated	
43	5500	95	12	45	.4	uncoated	
44	8500	144	12	30	Spec. ⊥	uncoated	
45	8500	155	12	30	Spec. =	uncoated	
46	8750	11	12	0	Spec. =	uncoated	
47	6250	9	12	0	Spec. =	uncoated	

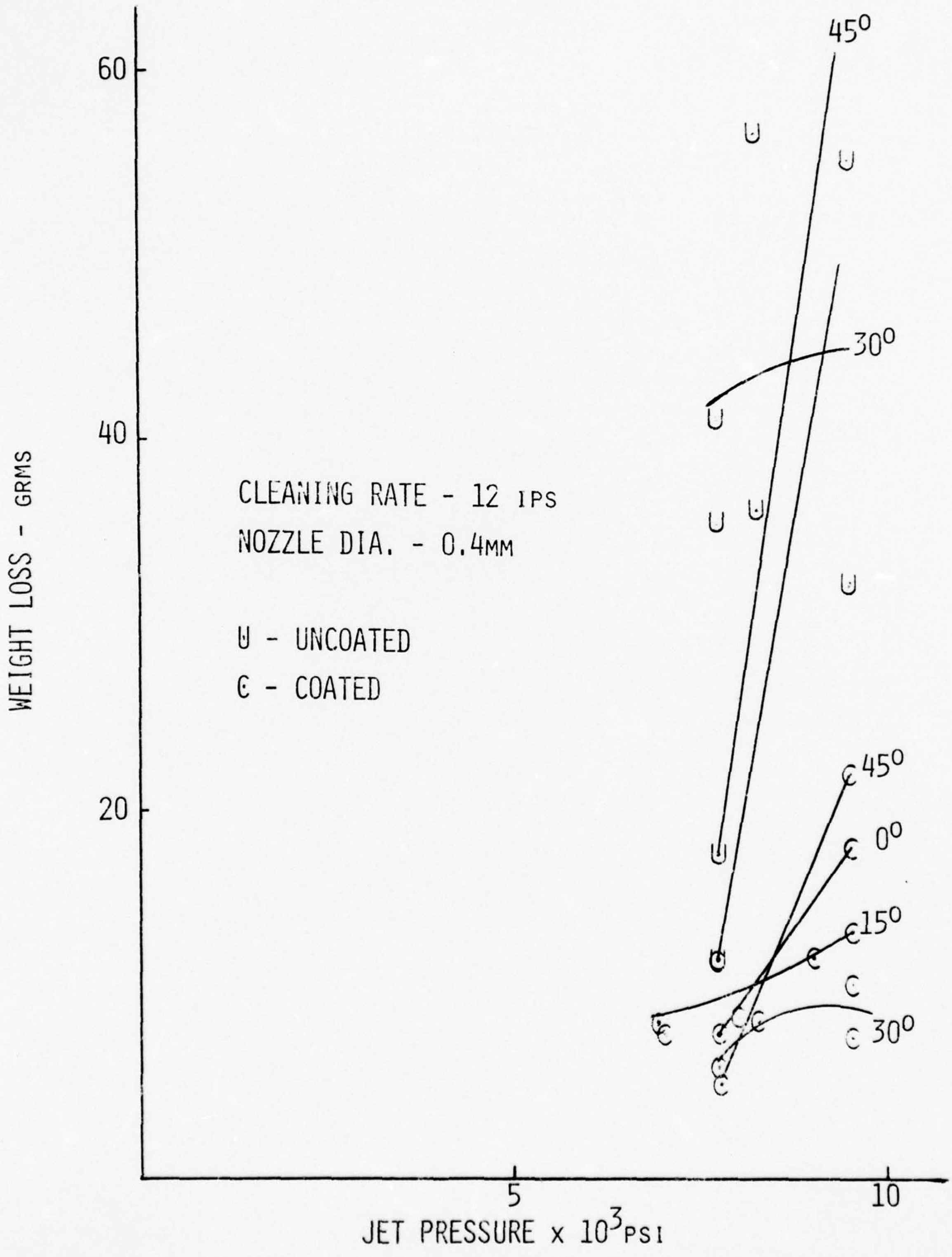

FIGURE 3.1 MASS LOSS VERSUS JET PRESSURE AT VARIOUS JET ANGLES

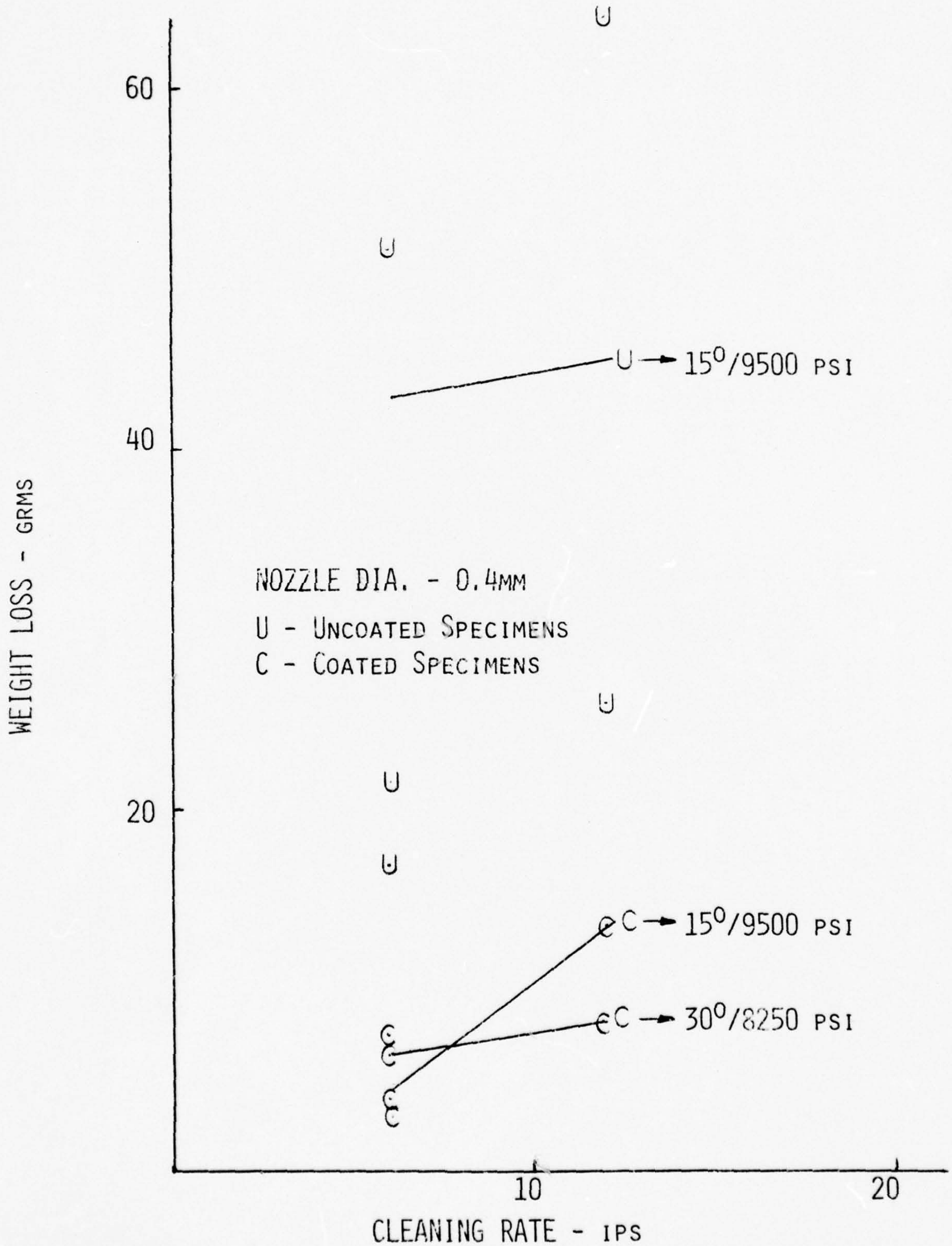

FIGURE 3.2 WEIGHT LOSS VERSUS CLEANING RATE AT VARIOUS JET ANGLES AND PRESSURES

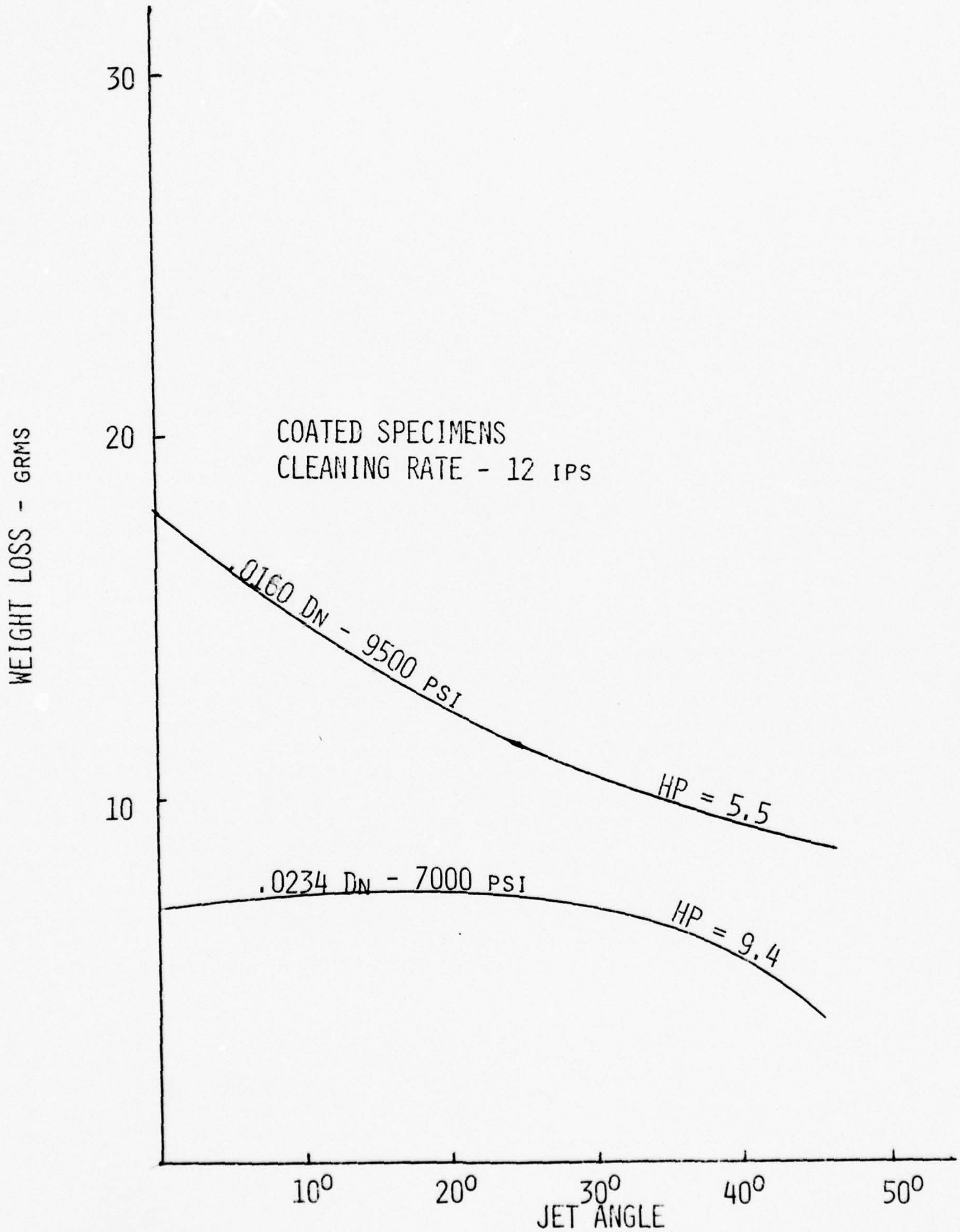

FIGURE 3.3 WEIGHT LOSS VERSUS JET ANGLE FOR VARIOUS NOZZLE SIZES AND JET PRESSURES

Figure 3.5 Coated Specimen Damaged By Water Jet

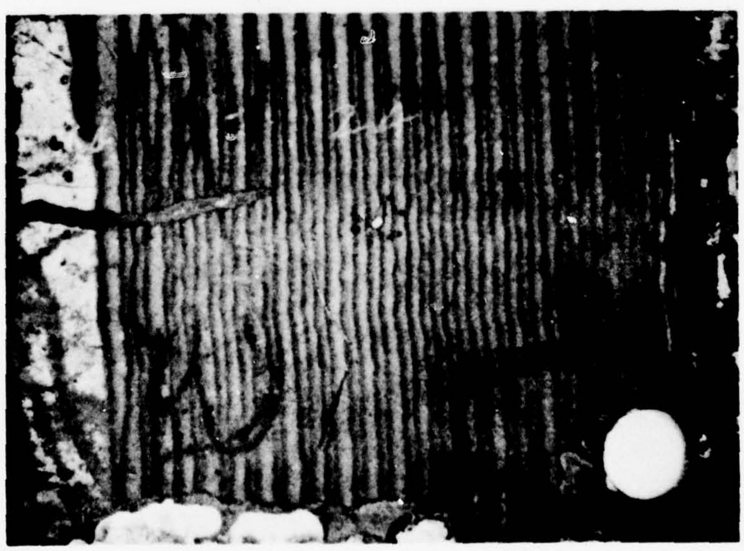

Figure 3.4 A Coated Specimen Cleaned By Water Jet

Figure 3.6 Uncoated Metal Specimen
Cleaning By Water Jet

smaller nozzle than the larger one and the specific energy of the smaller nozzle is better.

From the foregoing results, the operating conditions of a cleaning system should be at a rapid cleaning rate, small nozzle diameters, a low jet angle and an operating pressure consistent will power availability. These conditions must be modified on one point. The jet angle cannot be a low value for coated specimens. For uncoated specimens the foregoing conditions are valid. But for coated specimens the data in Table 3.1 indicates that the jet angle should not be below 30°. Jet angles less than 30° produced damaged to the antifouling paints. Above 30° the marine growth was removed and the antifouling coating remained intact. The condition of the coating was such that a smooth surface existed without any bare metal being exposed. Figure 3.4 shows a coated specimen that was cleaned, using a jet operating at 9,500 psi, .4mm nozzle, 12 ips cleaning rate at 45° jet angle. Note that the coating is intact and the marine fouling completely removed. Figure 3.5 shows another coated specimen cleaned by a jet operating at equivalent conditions, but at a jet angle of 0°. Note the removal of the coating down to bear metal along the path of the jet. Similar damage to the coating was observed for jet angles up to 30° over an operating pressure range of 6850 to 9500 psi. Figure 3.6 shows an <u>uncoated</u> specimen cleaning by a water jet operating at 7750 psi, .4mm nozzle diameter, 12 ips cleaning rate and 30° jet angle. The fouling is completely removed, the light areas being bare metal and the dark areas are stained metal surfaces.

Besides the circular nozzle geometry a sheet flow type nozzle was evaluated. The geometry of the nozzle is given in Figure 3.7. This nozzle was tested on uncoated specimens and the tests results are test no's 44 thru 47 in Table 3.1. The nozzle was tested under two conditions 1) the long dimension of the nozzle opening parallel to the cleaning motion and 2) perpendicular to the cleaning motion. Figure 3.8 shows the orientation

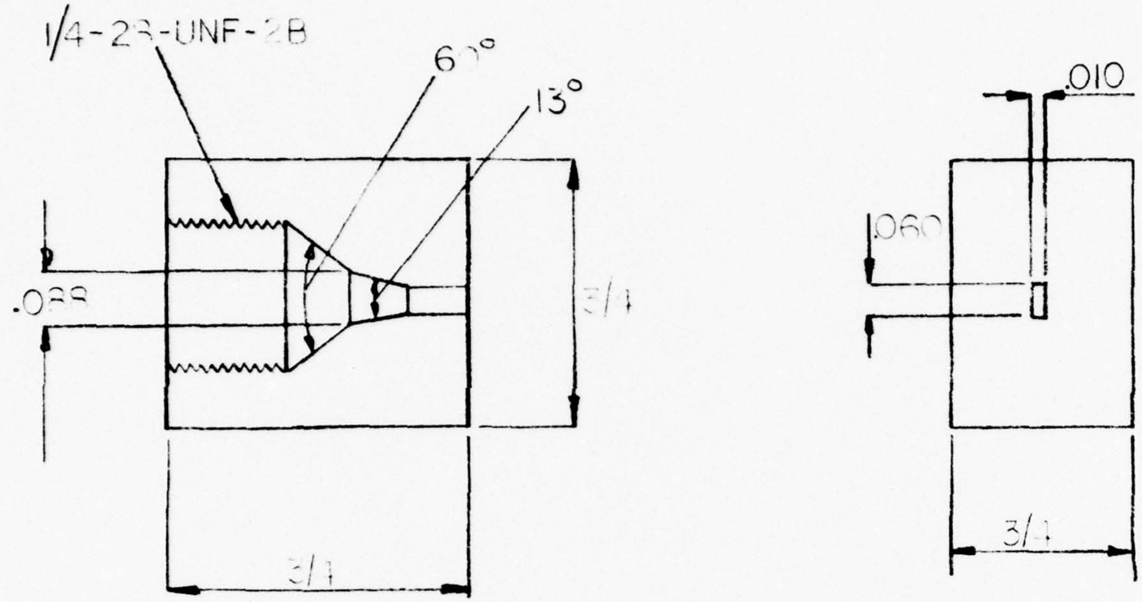

FIG. 3.7 ALTERNATE CLEANING NOZZLE GEOMETRY

of the nozzle under these conditions. The results from tests 44 and 45 indicate that the parallel direction is more effective in material removal than the perdendicular orientation under equivalent operating conditions. The results

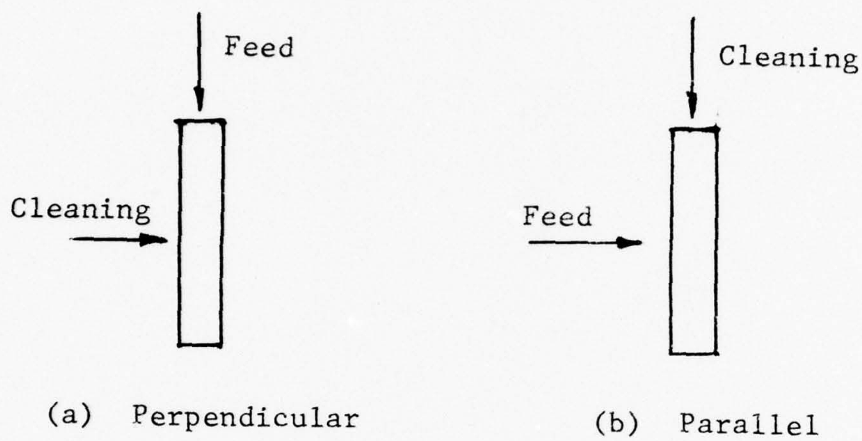

Figure 3.8 Nozzle Orientation For Alternate Cleaning Nozzle Tests

indicate that there is a 7.5% increase in cleaning capabilities for the parallel orientation as opposed to the perpendicular position. The jet angle was then changed to 0° while maintaining pressure and parallel nozzle orientation and there was a 92% decrease in the mass loss, indicating a high sensitivity to jet angle. This sensitivity is larger than that observed for the circular nozzles (refer to Figure 3.3). The last cleaning specimen was tested using the alternate nozzle geometry at a jet angle of 0°, and parallel orientation but at a reduced pressure level (6250 psi as opposed to a previous 8750 psi). The decrease in mass loss was 18%, but this is substantially lower than that observed for circular nozzles, indicating that operating pressure may not be as critical a variable for this nozzle geometry. A comparison of the circular nozzles and the alternate nozzle under equivalent conditions can be obtained by comparing

shots nos. 44, 45, 19, and 20. The jet pressures are not quite the same (differing by 3%) but the alternate nozzle shows a 275% increase in weight loss as compared to the circular nozzle. This does not establish the superiority of one nozzle over the other since the power outputs are not equivalent. For the circular nozzle the power output was 3.21 HP and for the sheet flow nozzle the power was 8.13 HP, while the specific energies are .0568 HP/grm and .0524 HP/grm respectively. Thus, both nozzles are approximately equal in efficiency at equivalent operating conditions. Thus, the judgement on which nozzle to use will be based on other considerations such as cost, wear, thrust, etc. The alternative nozzle has a thrust of 5.1 lb. while the circular nozzle has a thrust of 1.7 lb. under equivalent conditions, making the circular nozzle more attractive for diver use.

3.2 Metal Cutting Studies

In a parallel effort to the cleaning investigation the capabilities of a high pressure jet to cut metal underwater was undertaken. Figure 3.9 thru 3.15 show the results of the parameter investigation on 1020 steel specimens. Figures 3.9 and 3.10, 3.11 and 3.12, and 3.13 and 3.14 refer to the .3mm, .4mm, and .5mm nozzles respectively. For the .3mm curves, the data is quite scattered, but the general trend is increasing penetration with decreasing traverse rate as shown in Figure 3.9. Note the relatively high pressures needed to effect penetration. As will be shown later this nozzle is inefficient to the larger nozzles when compared on an energy basis. The exposure rate curve shown in Figure 3.10 is the basic performance curve for establishing performance (i.e., cutting time) and system size relations. The exposure rate is the product of the depth of penetration and the cutting rate and is directly related to the time required to cut through a given material thickness over a prescribed path. Figure 3.10 shows that the optimum has not been achieved, but should be at a cutting rate slightly greater than .5 ips.

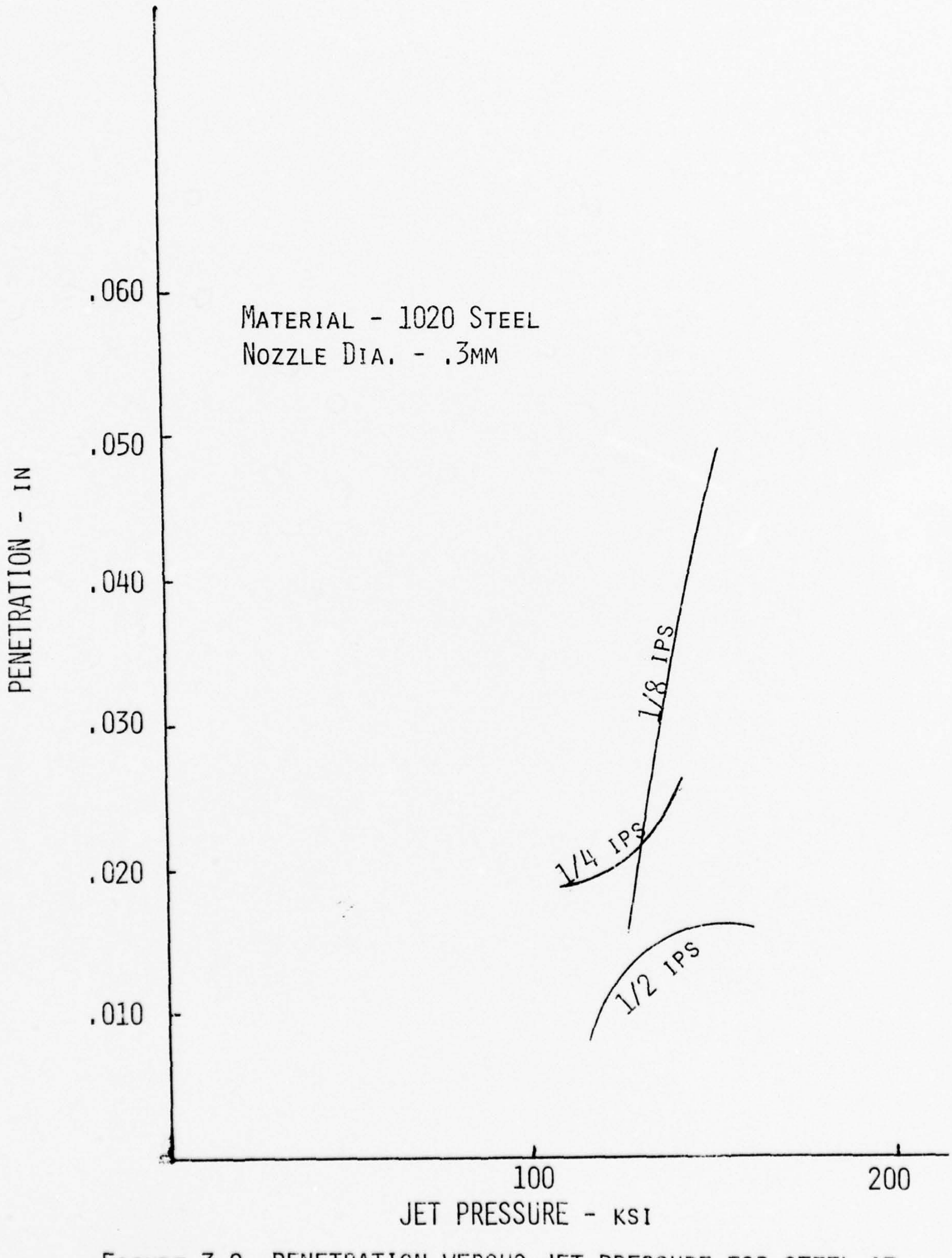

FIGURE 3.9 PENETRATION VERSUS JET PRESSURE FOR STEEL AT VARIOUS CUTTING RATES

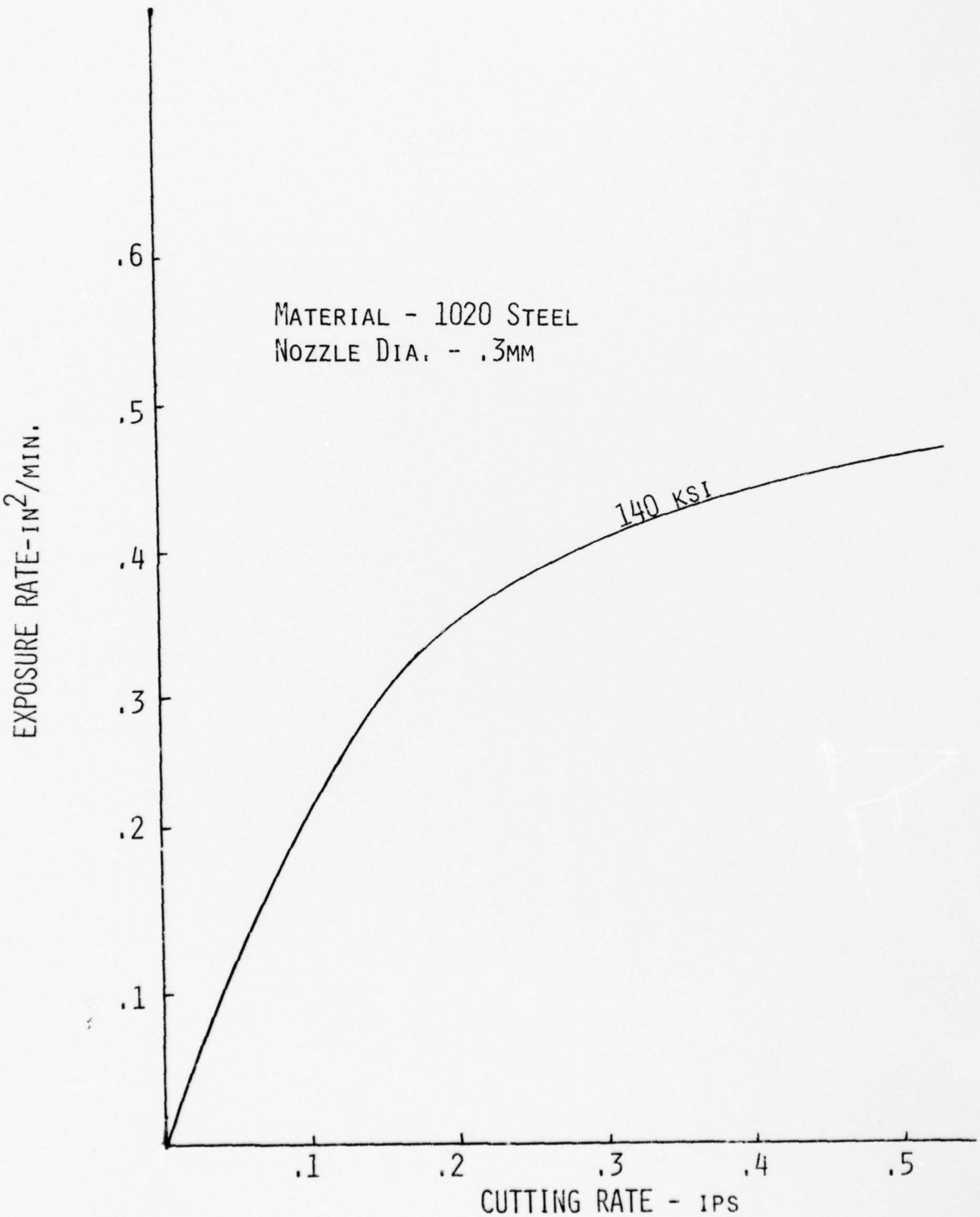

FIGURE 3.10 EXPOSURE RATE VERSUS CUTTING RATE FOR STEEL AT 140 KSI

The same type of trends appear in Figures 3.11 and 3.12 for the .4mm nozzle, but data is not as scattered as in the case of the .3mm. Note that the .4mm nozzle exposure rate is approximately double that of the .3mm; and, since the horsepower varies as the square of the nozzle diameter, for a constant pressure the exposure rate should be approximately double that of a .3mm. This should give a specific energy (i.e., ratio of energy input to unit area exposed) of approximately the same value. As shown in Figure 3.15 this is exactly the case. The performance curves for the .5mm nozzle are shown in Figures 3.13 and 3.14. Note the lower jet pressures required to effect equivalent penetrations. This should have an effect on the specific energy since the horsepower is proportional to:

$$HP \propto D_N^2 \, (\Delta P)^{3/2}$$

where D_N is the nozzle diameter

ΔP is the jet pressure.

As shown in Figure 3.15 the .5mm curve is distinctly below that of the .3mm and .4mm. This indicates that the larger nozzle diameters are more efficient, on an energy basis, and it also makes the hardware more attractive since the operating pressures are reduced, hence reliability, component size, and maintainability should be better as well as lower fabrication costs. Note, also that all the exposure rate curves indicate that the optimum cutting rate is near .5 ips, but the maximum penetration occurs at the lower cutting rates. The value of these curves is that the performance is specified over a wide range of cutting rates, and the trade-off between penetration and exposure can be made to suit a particular application.

The performance curves define the minimum system size (i.e., the choice of nozzle diameter and jet pressure determine the horsepower of the system). Improvements on the overall system performance can be obtained through the use of fluid additives, abrasives, and jet angling as augmentation techniques. Figure

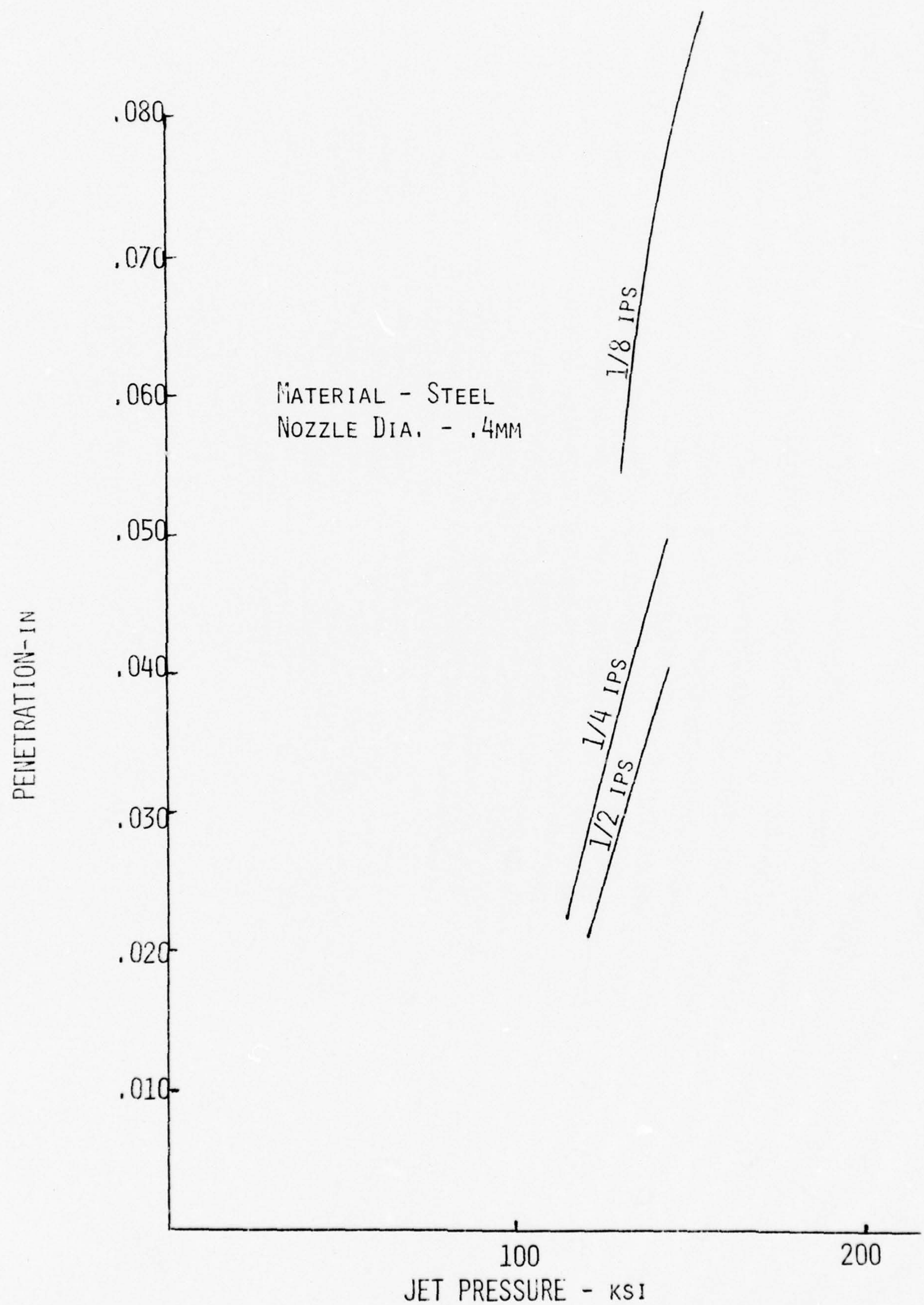

FIGURE 3.11 PENETRATION VERSUS JET PRESSURE FOR STEEL AT VARIOUS CUTTING RATES

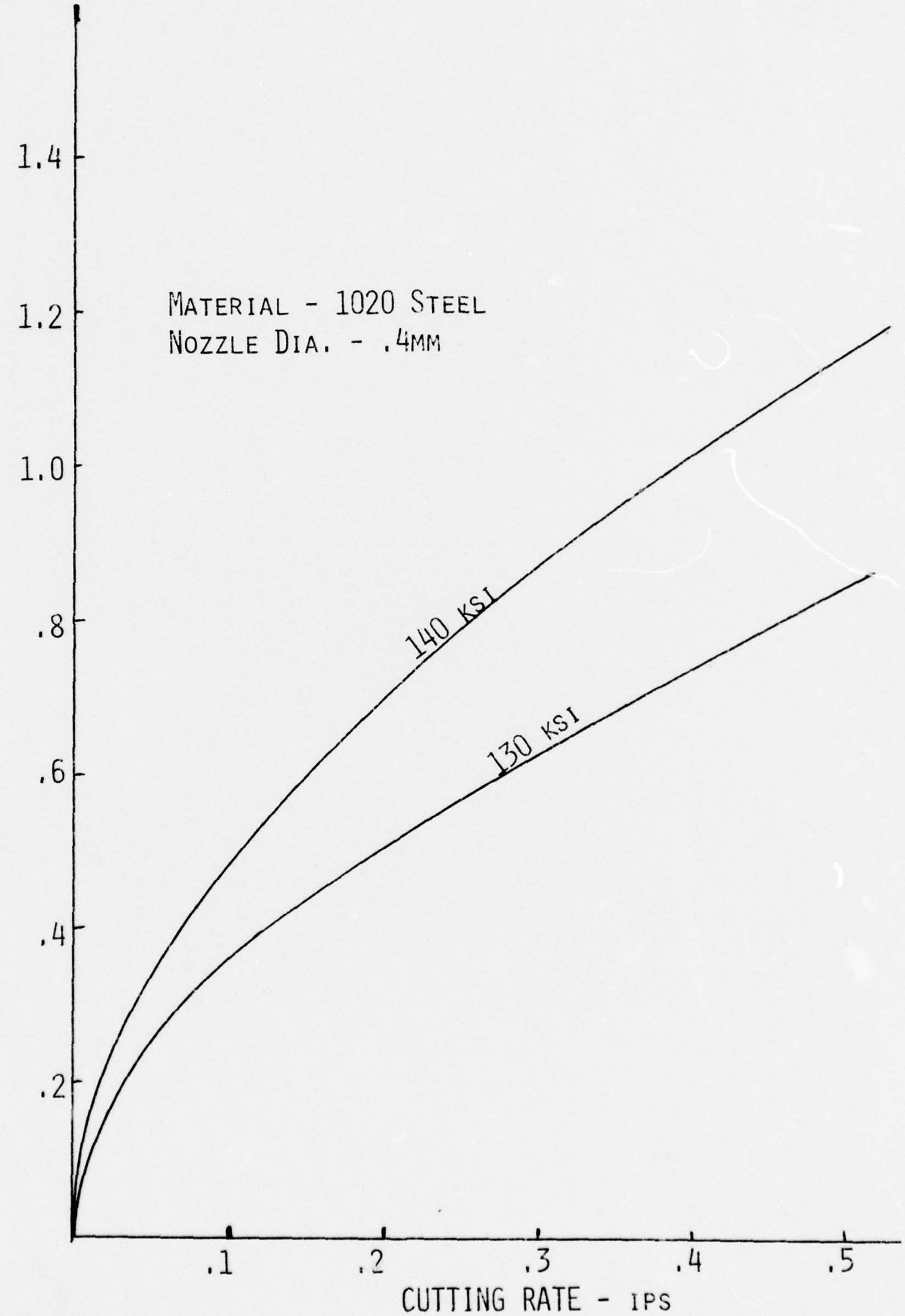

FIGURE 3.12 EXPOSURE RATE VERSUS CUTTING RATE FOR STEEL AT VARIOUS PRESSURE LEVELS

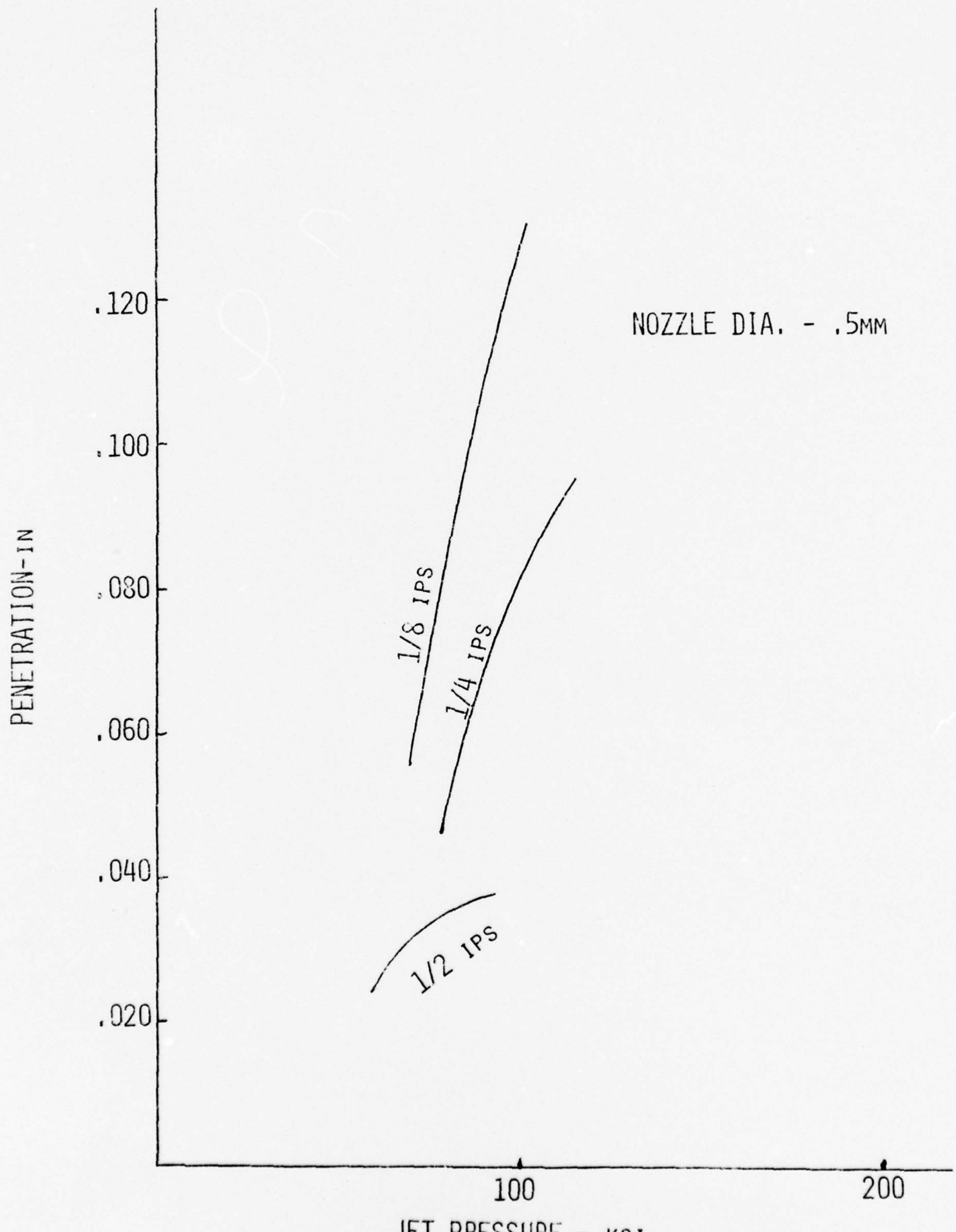

FIGURE 3.13 PENETRATION VERSUS JET PRESSURE FOR STEEL AT VARIOUS CUTTING RATES

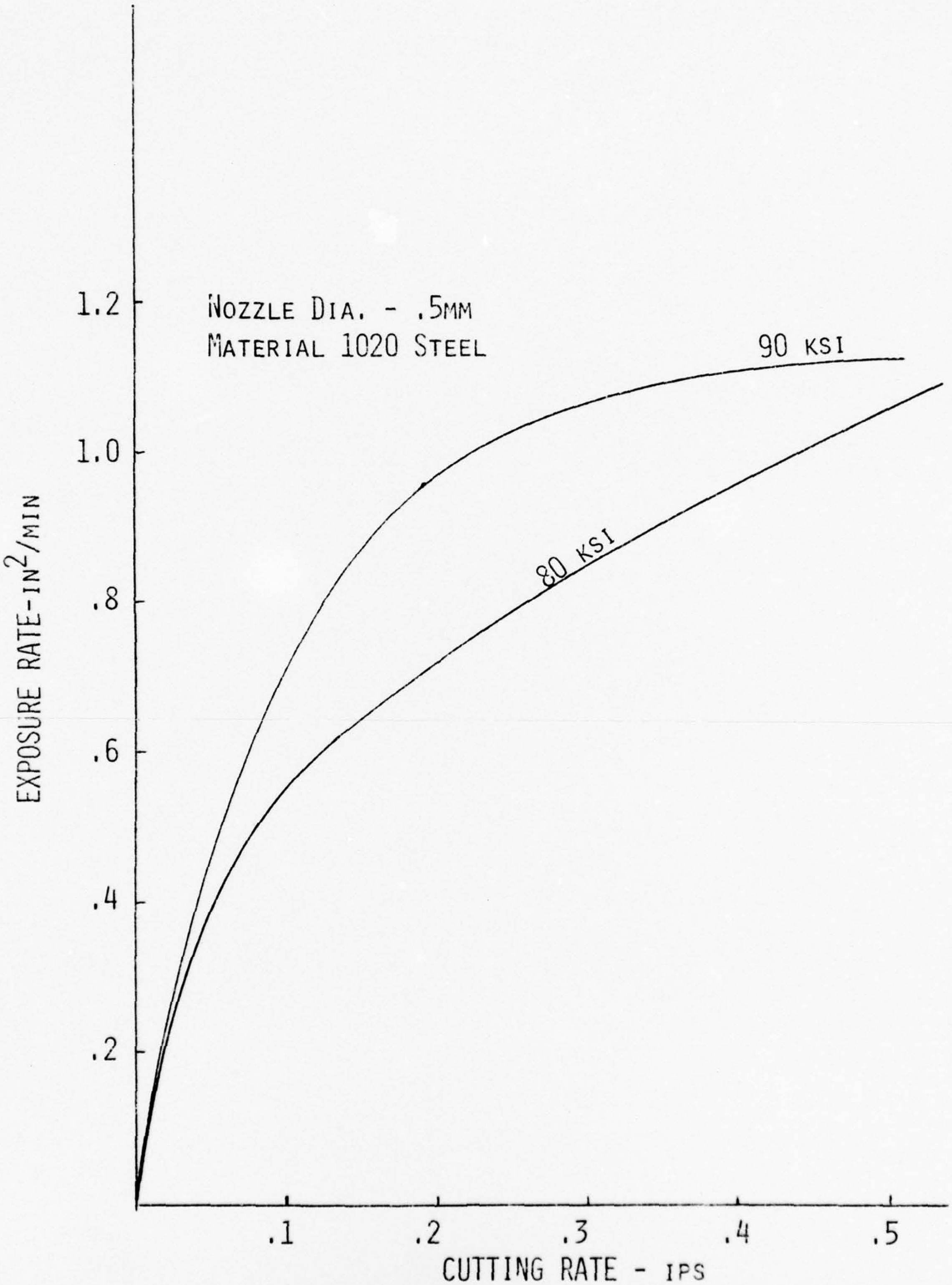

Figure 3.14 EXPOSURE RATE VERSUS CUTTING RATE FOR STEEL AT VARIOUS JET PRESSURES

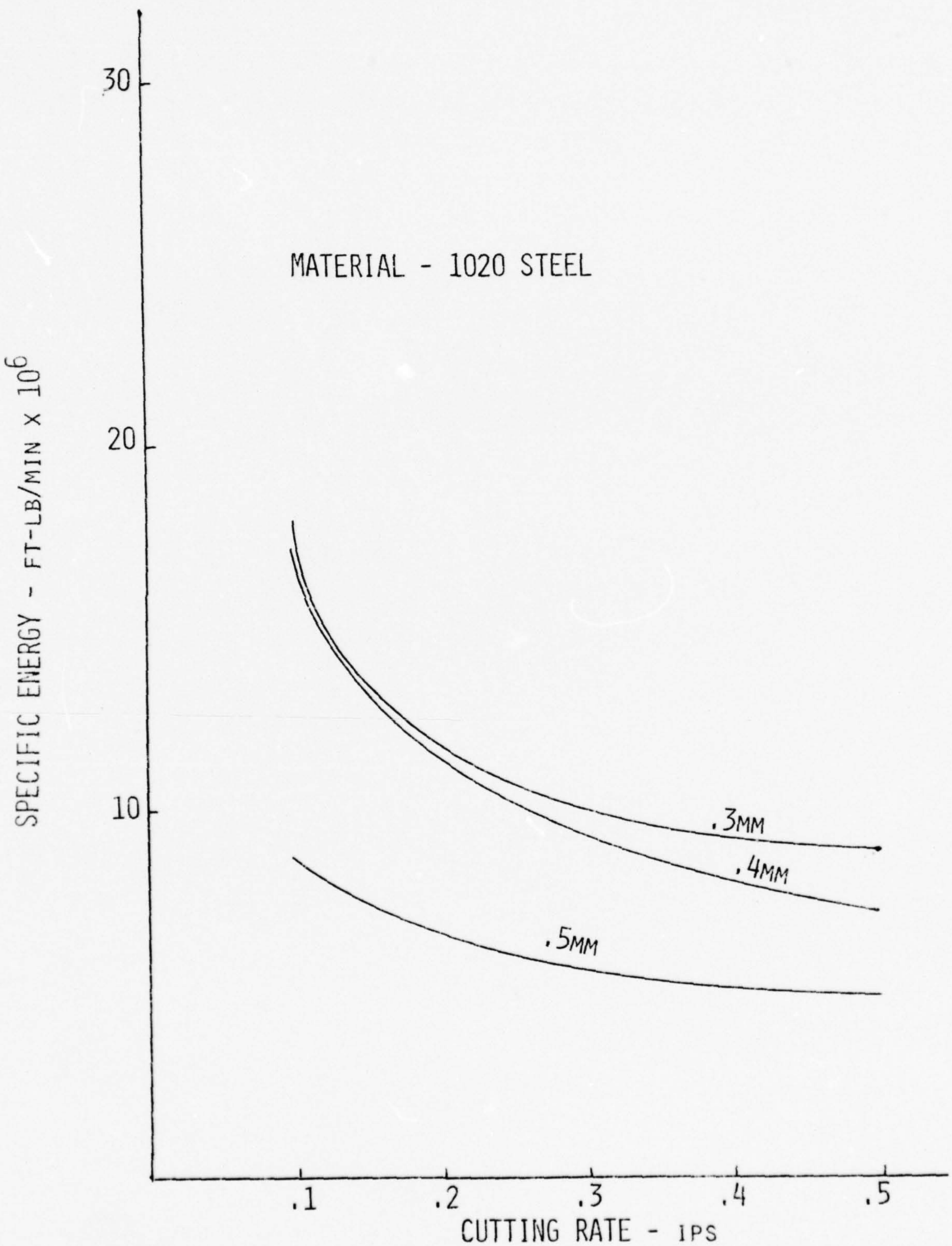

FIGURE 3.15 SPECIFIC ENERGY VERSUS CUTTING RATE AT VARIOUS NOZZLE DIAMETERS

3.16 shows the effect of jet angle on penetration for 1020 steel specimen for a .4mm nozzle. Note the increase in penetration (32 to 45%) at 15^{o} jet angle as opposed to 0^{o} jet angle. Figure 3.17 shows a similar trend for a .5mm nozzle. The jet angle is measured from the vertical perpendicular to the surface and the center line of the incoming jet. Angles of a positive rake (i.e., the angle measured from the metal surface to the center line of the incoming jet in a counter clockwise manner is greater than 90^{o}) were investigated.

Figures 3.18 and 3.19 show the effects of different types of abrasives on the penetration of steel specimens. Several different abrasives were introduced downstream of the jet by bonding sheets of the material to the metal surface. The abrasives investigated included fiberglass, marble, and transite (cast concrete and asbestos). Note that in the pressure regimes investigated the abrasives do not contribute to increasing the penetration capabilities of the jet, except for the marble. One point concerning the use of fiberglass should be noted; for higher pressures, approximately 100,000 psi and beyond, the fiberglass should contribute to increasing the jet penetration. This "effective" pressure may be due to working in an underwater environment. Previous reported results have shown an increase for all jet pressures, but these investigations were carried out in air. This "effective" pressure may be caused by the hydrodynamic drag on the accelerated abrasive particles, the virtual mass of the abrasive particle and the water surrounding it. Also, since the abrasive materials were bonded directly to the surface the thickness of the abrasive sheet was the characteristic distance associated with the acceleration of the particle. This distance may have been too short to allow the particle to reach the terminal jet velocity. Since the energy stored in the particle (i.e., its capacity to remove material on impact) varies as the square of the velocity a significant amount could be lost, causing a decrease in the effectiveness of the abrasive. Alternate methods of intro-

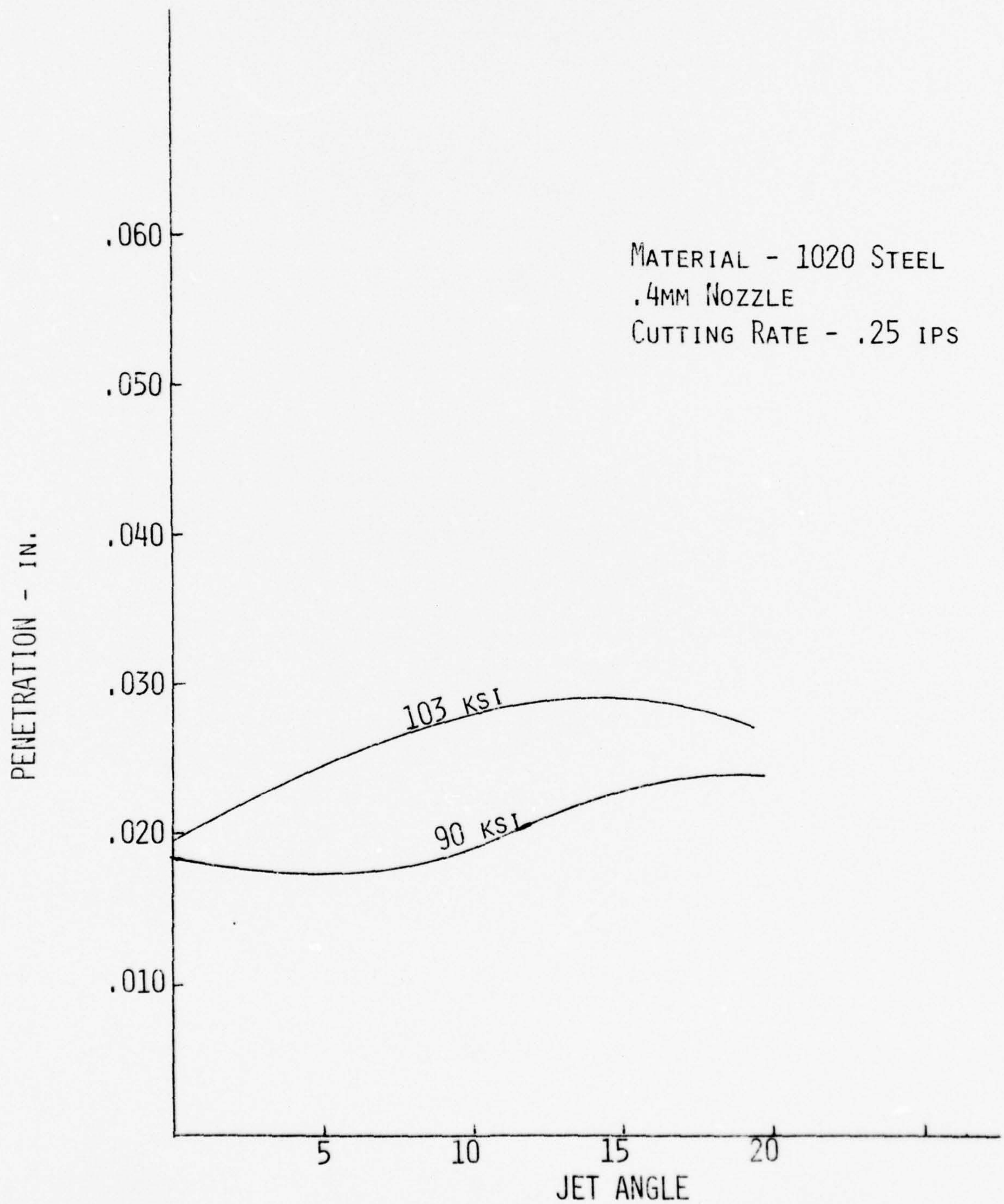

FIGURE 3.16 PENETRATION VERSUS JET ANGLE FOR STEEL AT VARIOUS PRESSURE LEVELS

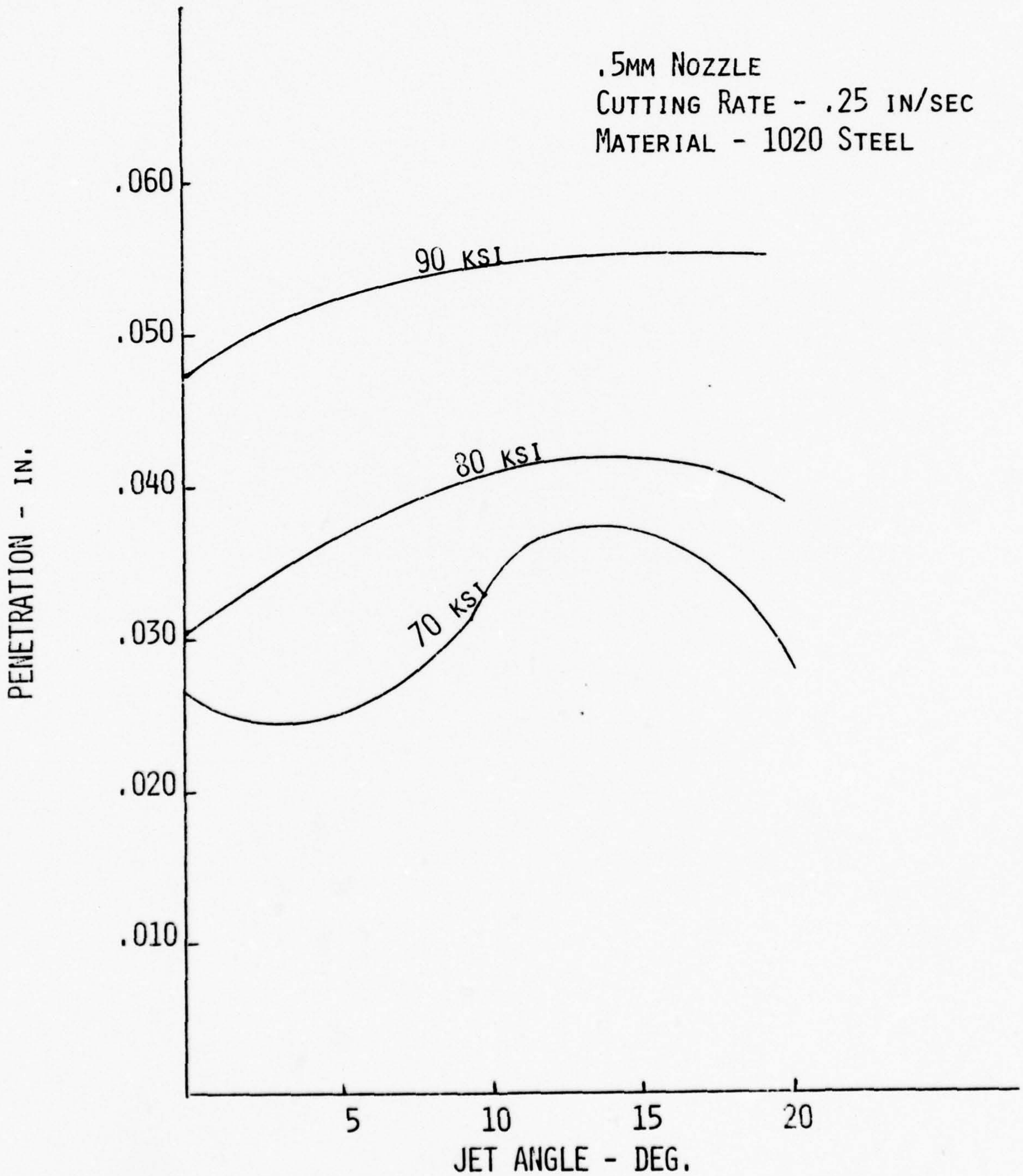

FIGURE 3.17 PENETRATION VERSUS JET ANGLE FOR STEEL AT VARIOUS PRESSURE LEVELS

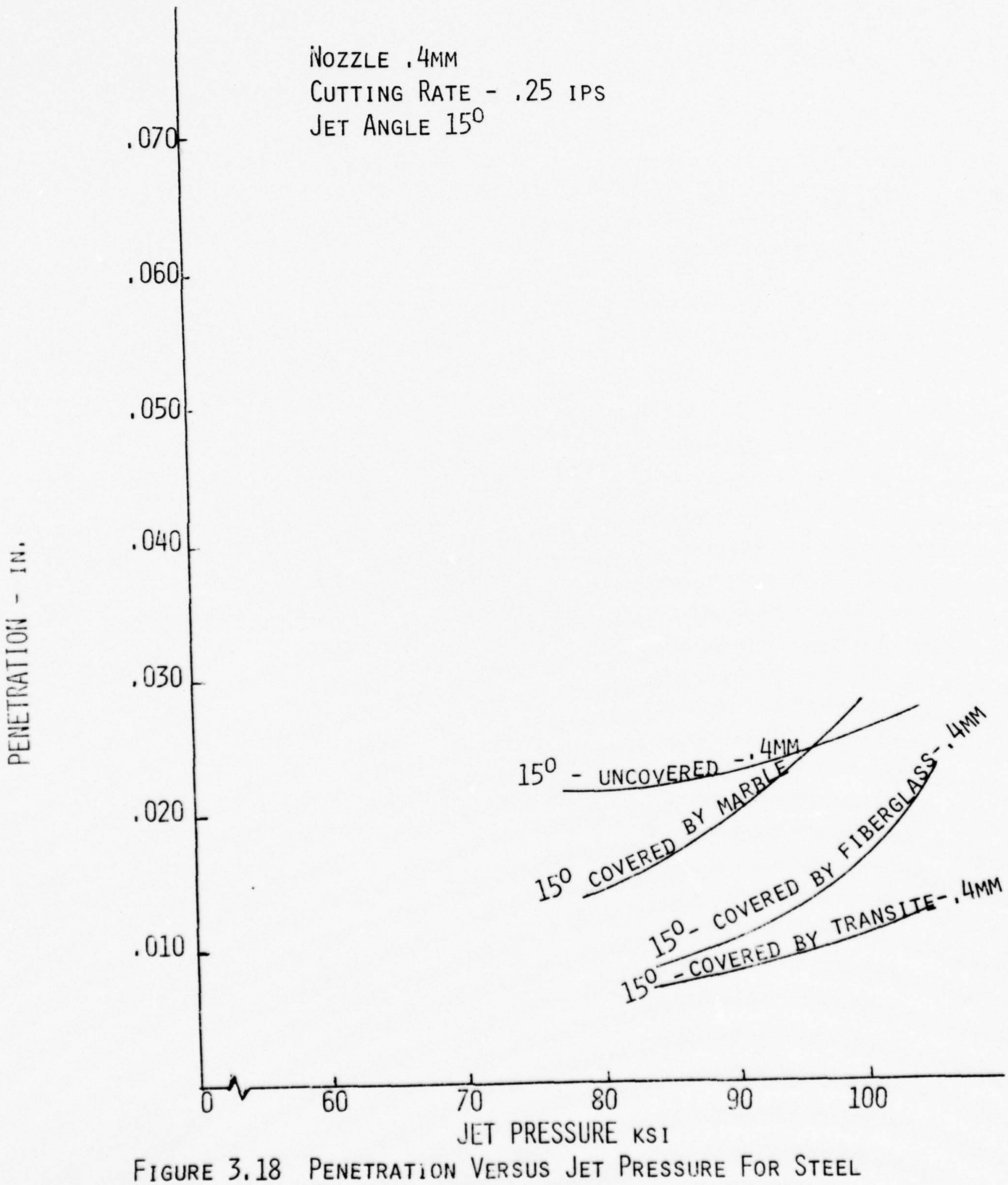

FIGURE 3.18 PENETRATION VERSUS JET PRESSURE FOR STEEL FOR VARIOUS TYPES OF ABRASIVES

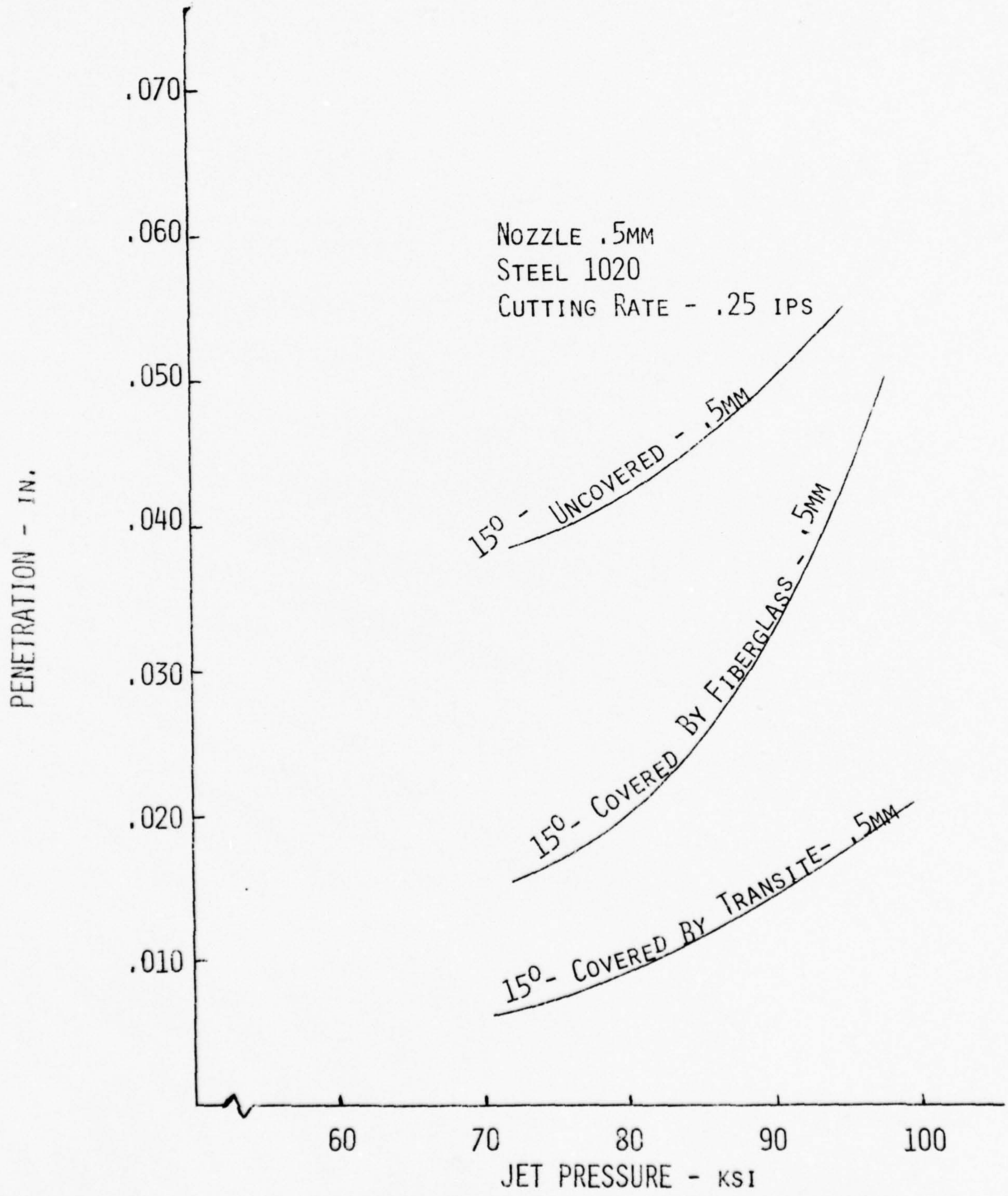

FIGURE 3.19 PENETRATION VERSUS JET PRESSURE FOR STEEL FOR VARIOUS TYPES OF ABRASIVES

ducing the abrasive such as an abrasive feed nozzle may provide better performance.

In addition to the jet angle and abrasive, the addition of long chain polymer additives directly to the jetting fluid was investigated. The polymer used is manufactured by NALCO Chemical Company under the trade name BX-254. The effect of this additive is illustrated in Figures 3.20 and 3.21. Pure water, 0.1% BX-254, and 0.25% BX-254 (percentages given by weight in water) were utilized, with both .4mm and .5mm diameter nozzles, under identical cutting conditions. Penetration was increased significantly, at nozzle pressures above 80,000 psi for both nozzle diameters when the 0.1% BX-254 solution was used. At pressures above 80,000 psi both nozzles are operating at Reynold's numbers in the range covered by the Universal Resistance Law ($Re > 10^5$). In this Reynold's number regime, the effective friction coefficient of the jet at the nozzle depends upon the fluctuating velocity components of the jet. The addition of the polymer to the jet solution serves to reduce the fluctuating velocity components in the nozzle, reducing the frictional drag and lowering the free stream turbulence of the jet which effectively increases the penetration potential of the jet.

Using the best combination of jet pressure, nozzle size, jet angle, abrasives and fluid additives, additional tests were performed on samples of HY 80. Figures 3.22 and 3.23 show the results of the testing and a comparison of the various combinations. Note, in Figure 3.22 that the 0.1% BX-254, non-abrasive jet provides better performance than the water only jet for a .4mm nozzle, while in Figure 3.23 the reverse is true for a .5mm nozzle. This change in effects with increasing nozzle size may due to the inability of the additives to reduce the free stream turbulence and retard jet breakup. Figures 3.24 and 3.25 show typical HY 80 specimens

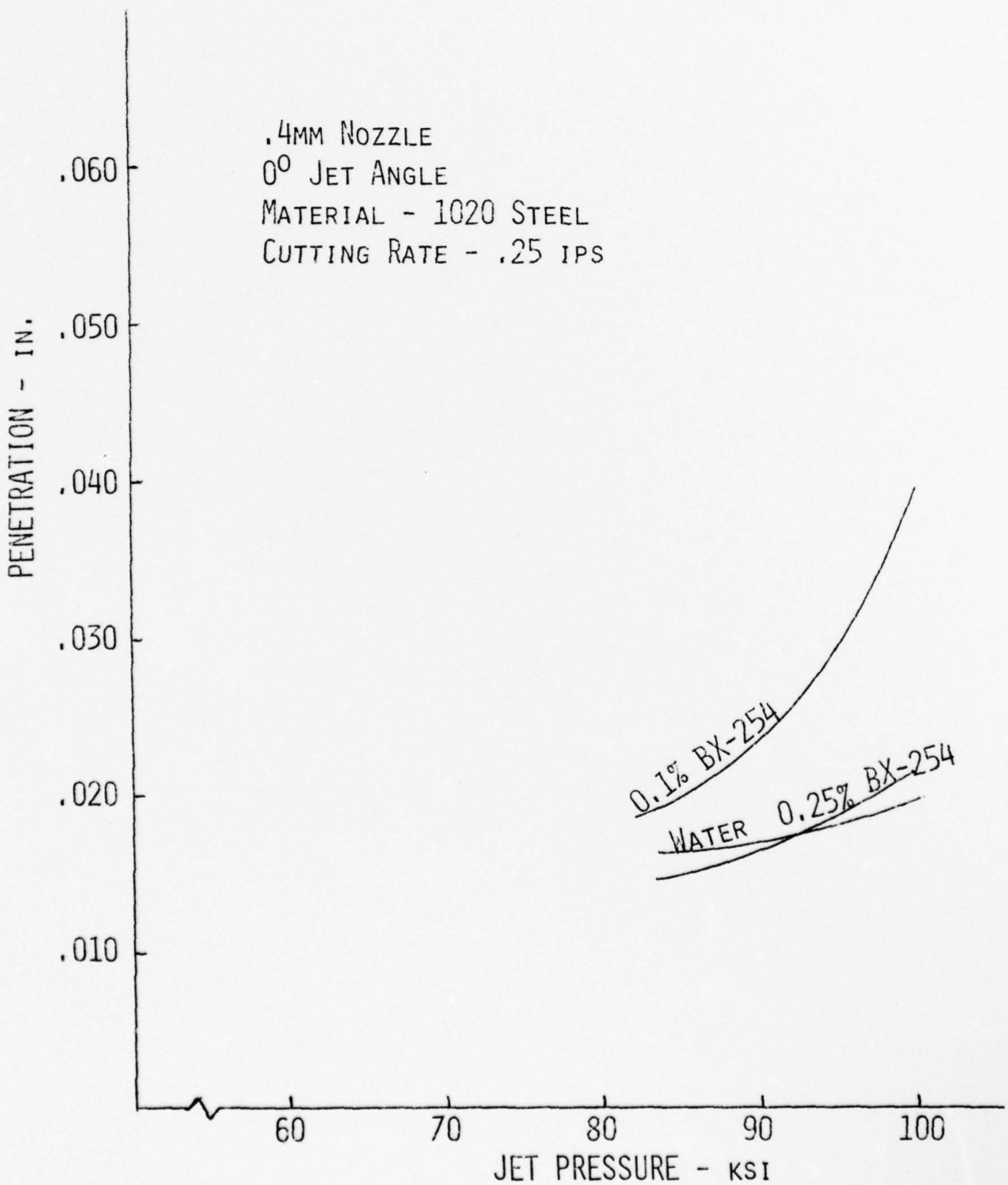

FIGURE 3.20 PENETRATION VERSUS JET PRESSURE FOR STEEL FOR VARIOUS POLYMER CONCENTRATIONS

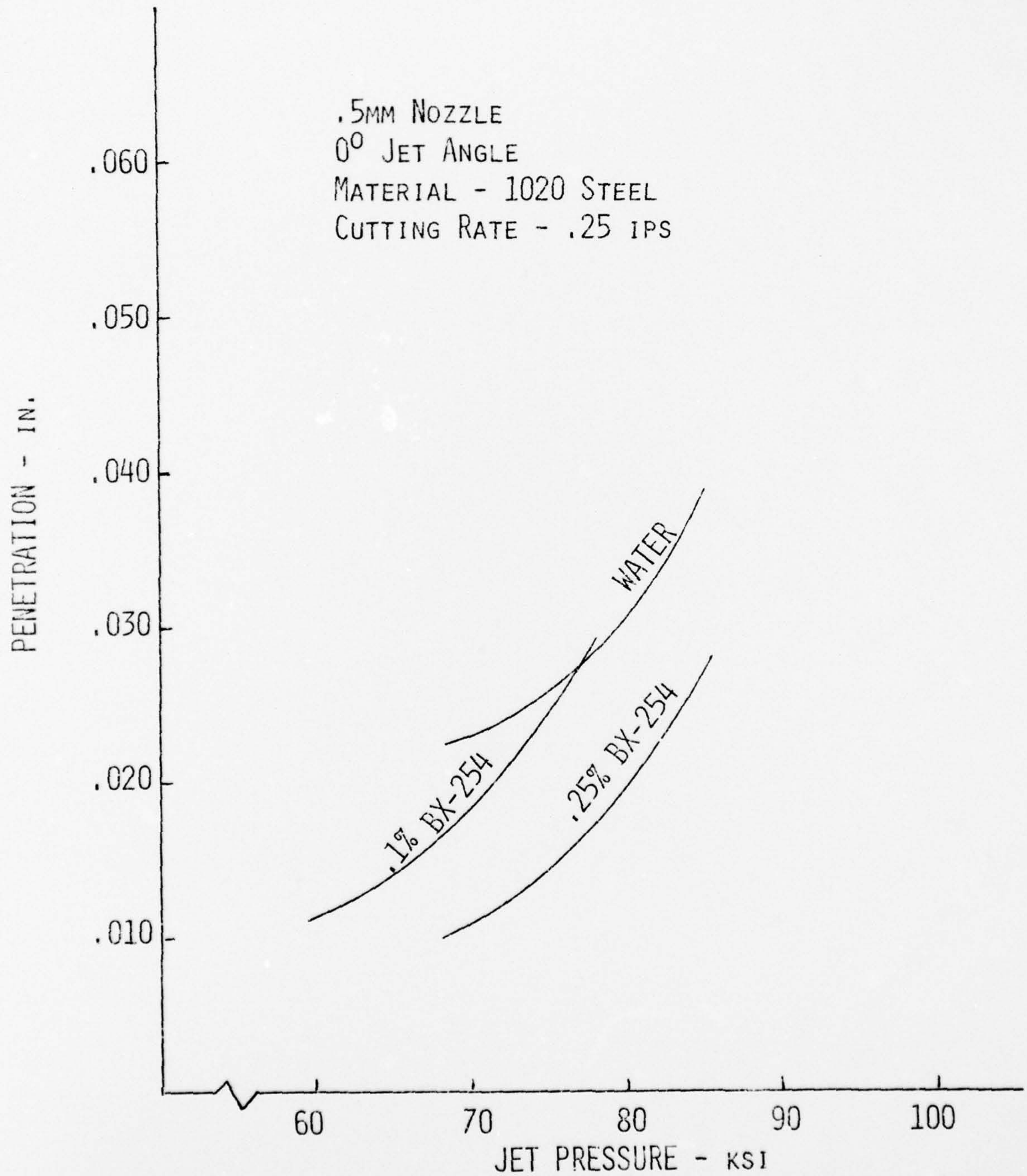

FIGURE 3.21 PENETRATION VERSUS JET PRESSURE FOR STEEL FOR VARIOUS POLYMER CONCENTRATIONS

that were cut by the water jet. Figures 3.26 and 3.27 show typical 1020 steel specimens cut by the water jet. Note in figure 3.27 the hole that was drilled through the specimen using the jet.

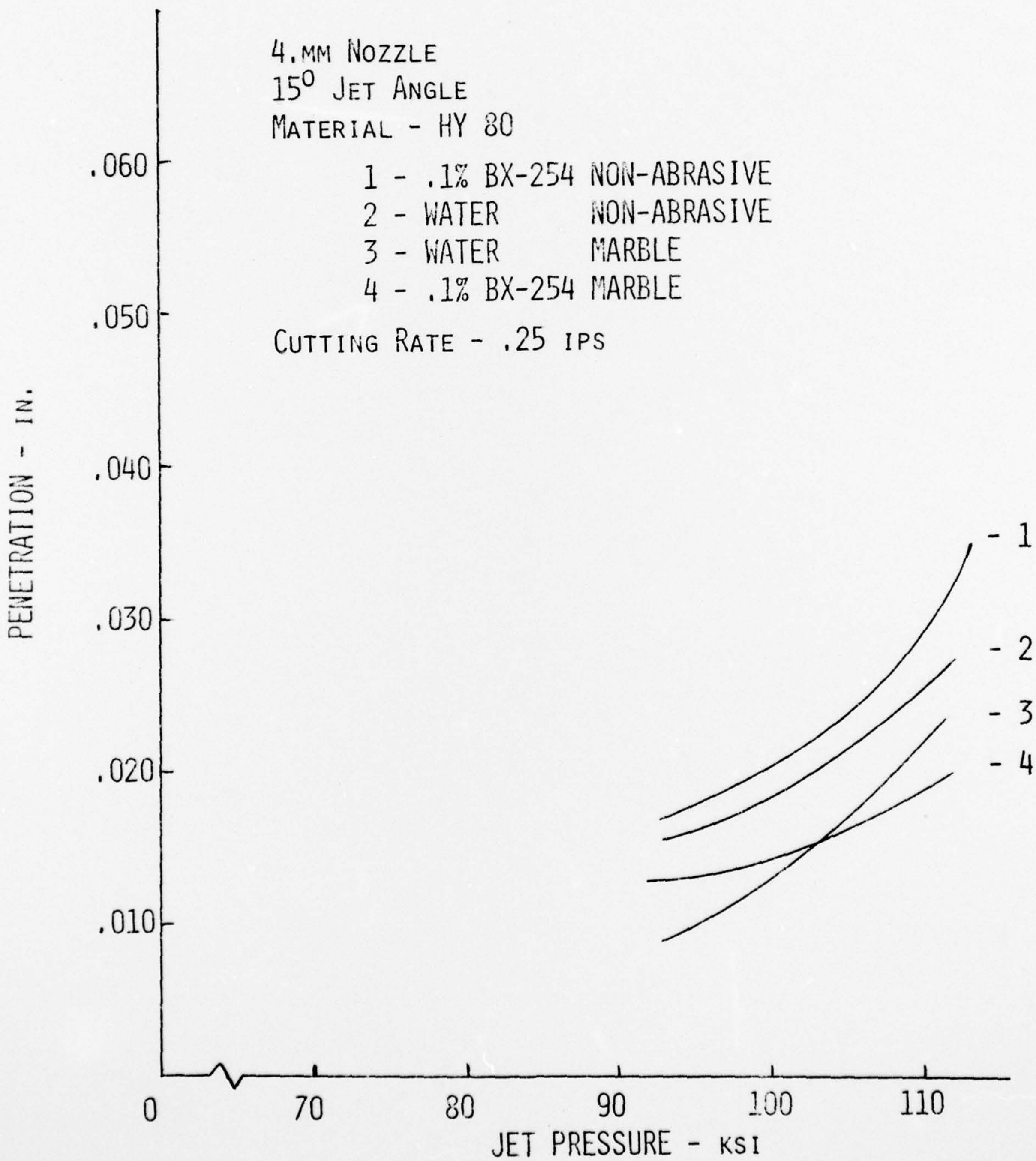

FIGURE 3.22 PENETRATION VERSUS JET PRESSURE FOR HY 80 STEEL

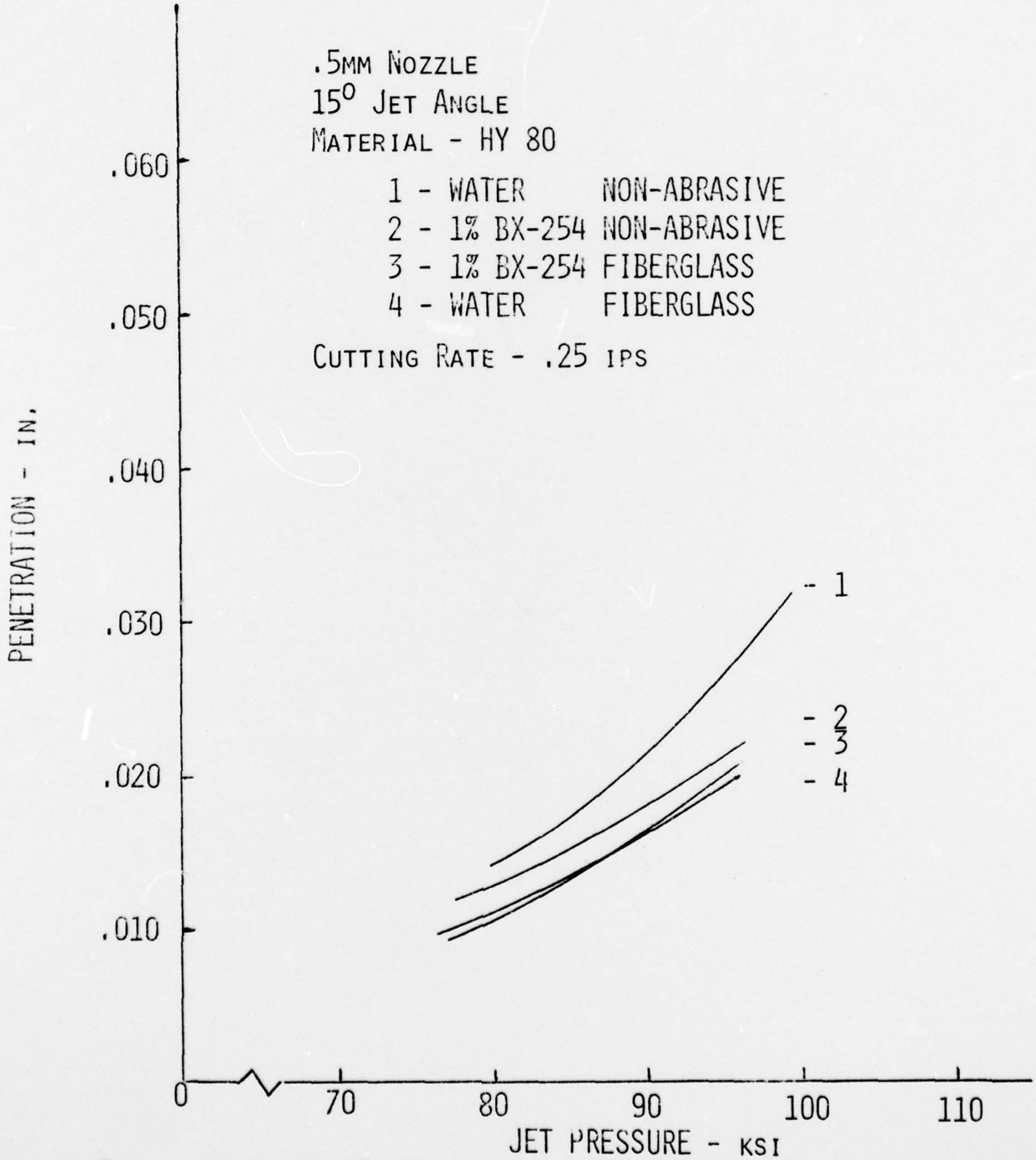

Figure 3.23 PENETRATION VERSUS JET PRESSURE FOR HY 80 STEEL

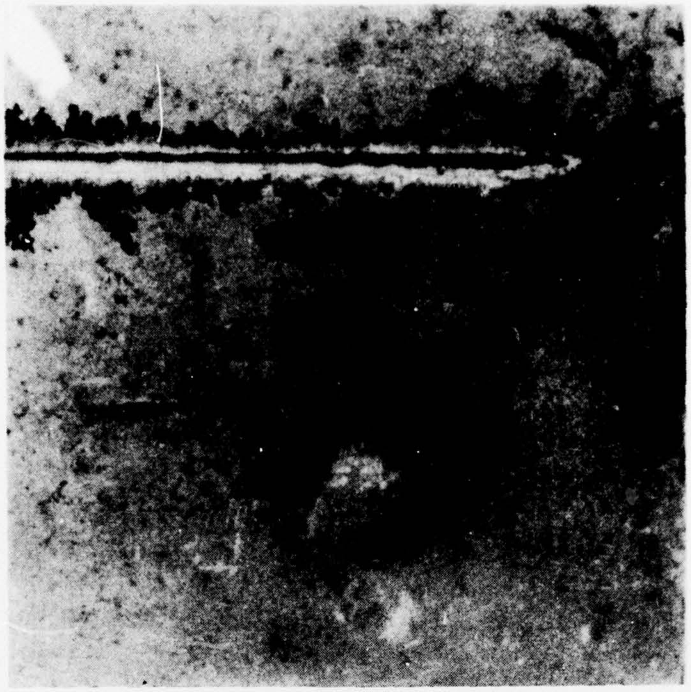

Figure 3.24 HY 80 Steel Specimen Cut By Water Jet

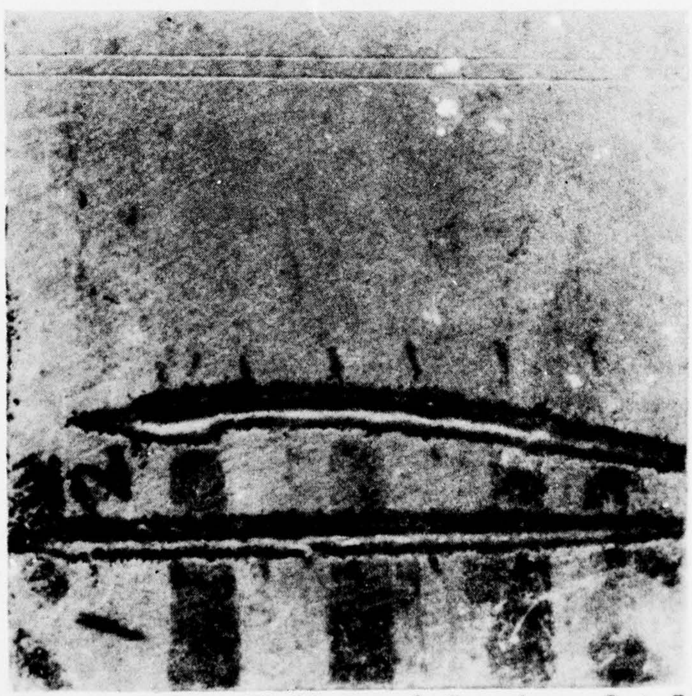

Figure 3.25 HY 80 Steel Specimen Cut By Water Jet

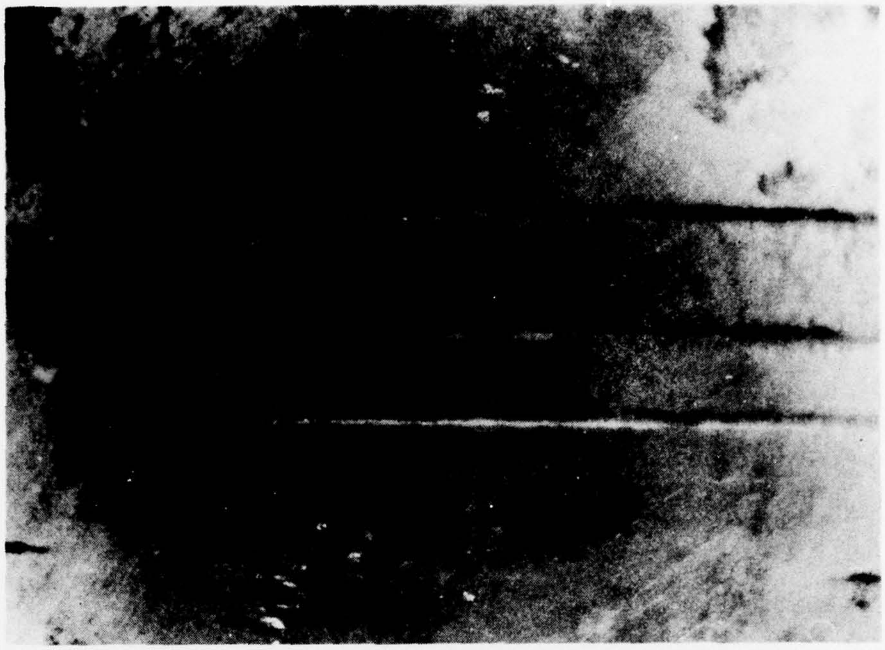

Figure 3.26 1020 Steel Specimen Cut
By Water Jet

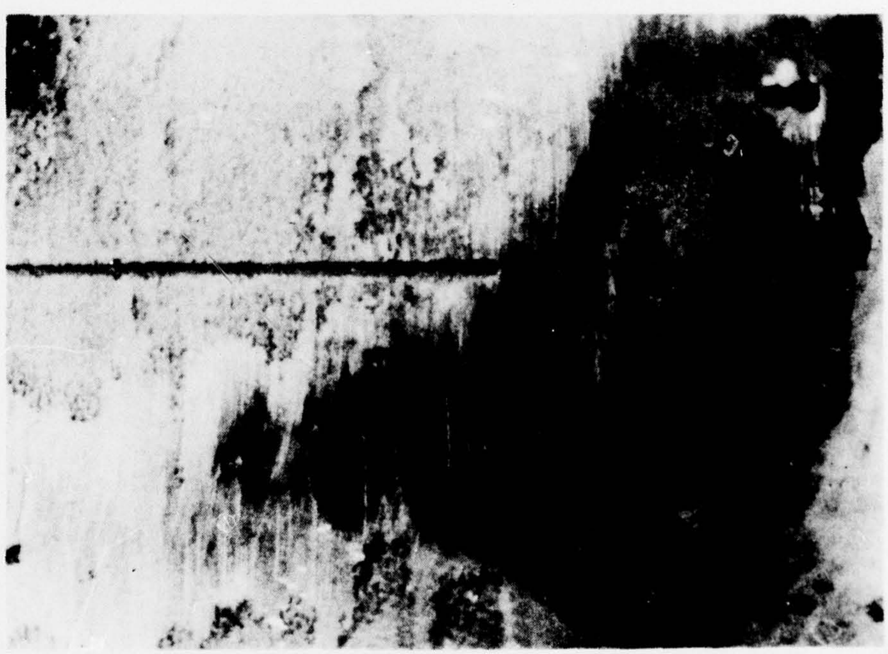

Figure 3.27 1020 Steel Specimen Cut
By Water Jet

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Cleaning Studies

The results of the cleaning studies have clearly demonstrated the capability of the water jet to remove marine fouling from submerged surfaces. In addition, it has also demonstrated the ability to remove fouling from submerged surfaces that have an anti-fouling paint coating without damage to the coating. This capability is not currently available in present methods. The pressure regimes are relatively low (6000-9000 psi) and pumping systems of sufficient capacity are available to meet the demands. Commercial hardware for the pumps, valves, hose, fittings, etc. are all currently available or can be modified for underwater use at minimal cost and time expenditures. Since the pressure regime is relatively low, flexible hose can be used to convey the high pressure water from the power source to the cutting nozzles. The use of flexible lines gives the water jet technique added dimension for cleaning areas accessible by divers only. The power source can be bottom or surface mounted and the high pressure water piped to the cleaning nozzles.

One area that still needs development is the use of seawater as the primary jetting fluid. Filtration methods can be used to filter the bulk contaminants from the seawater, but materials must be changed to be compatible with the marine environment. Possible candidates include stainless steel and nickel-chromium alloys.

Because the power levels for the cleaning are modest an integrated tool package is also feasible. The tool package

would contain the nozzle/lance, intensifier and primary power source. A portable diver operated system is definitely feasible. Figure 4.1 shows a miniature hydraulic power unit capable of 4 to 5 HP output and is only 9-1/2" long x 3" diameter and weighs 10#. This unit is currently under development by IITRI and will be ready approximately June, 1976. A unit similar to this could be developed using a closed-cycle-turbine for primary power to provide complete diver freedom.

The intensifier can be integrated into the pumping system to complete the power source. A variety of cleaning heads could then be developed and adapted to the common source. Thus, the cleaning system would be a versatile tool available to the diver for use in underwater cleaning, scouring, etc.

The concept of water jet cleaning of ship hulls has been clearly demonstrated, and a prototype system should be developed utilizing this technique. Before developing this prototype a cost/effective analysis should be undertaken to determine the most optimum configuration of such a cleaning system based on economic considerations. Using this cost analysis and the performance data generated in this study, a trade-off between cost of operation and a realistic tool size can be made. Once this is completed a prototype system can be fabricated. The data generated during the prototype development would form the basis for a underwater divers tool to meet the needs of the Navy in the area of ship hull cleaning.

4.2 Metal Cutting Evaluation

Cutting of metal under water has been demonstrated using high pressure water jets. The effects of the primary parameters have been investigated. The best performance was obtained using the larger nozzles (.5mm and .4mm) and jet

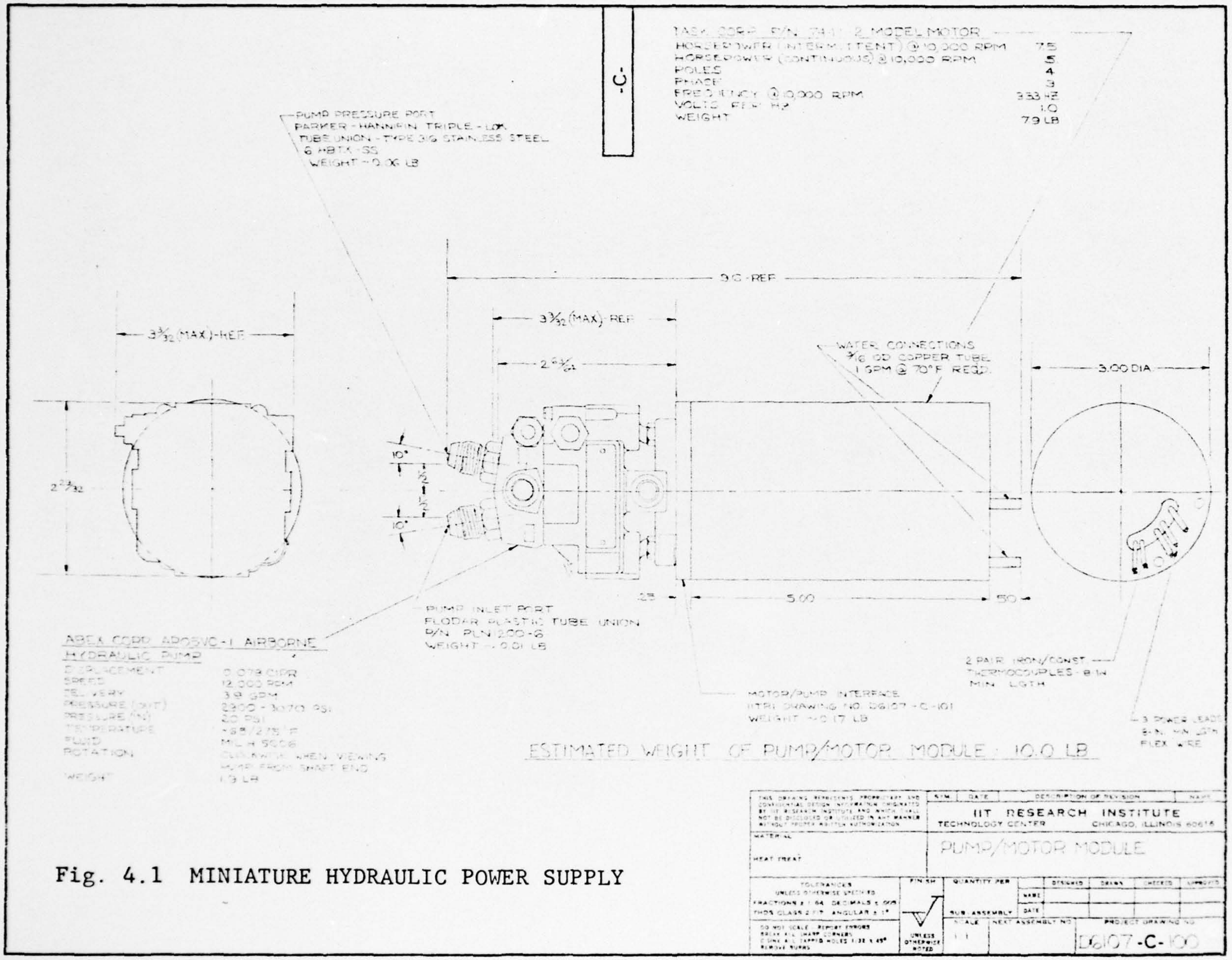

Fig. 4.1 MINIATURE HYDRAULIC POWER SUPPLY

pressures of 80,000 to 100,000 psi. Fluid additives and jet angling produced significant gains in penetration without additional horsepower expenditures. The results using abrasive addition are inconclusive and in conflict with observed data under ambient conditions. This difference may be due to the method of feeding the abrasive into the stream and the drag of the surrounding media.

If such a system were to be implemented certain systems considerations must be considered. First, the power requirements for continuous operation are substantial (in the range of 125 to 200 HP). This would require a surface mounted power source or a bottom source operating on a duty cycle. The technology to provide either of these units is available, but their impact on the overall system performance and cost is substantial.

The most important consideration of the systems feasibility is the operation and reliability of the intensifier in the marine environment.

Present intensifier technology is based on linear intensifiers and hence their limitations. IITRI and other organizations active in the field have developed this particular type of intensifier to the limits of its capabilities. There are four major areas which limit this type of intensifier:

1) packaging limitations - linear devices suffer from excessive package size as power requirements increase.
2) seal problems - most linear devices use positive "no-leakage" type of seals, hence seal wear is a definite problem. If "controlled clearance" types of seals are employed excessive vibration and shock can occur when operating at the required piston velocities.

3) pulsations - the best linear intensifier is a double acting unit that requires substantial buffering to damp out pulsations. These pulsations can cause excessive damage and the cost to damp them is excessive.

4) reliability - because of seal problems the reliability of these units is low, especially in regards to long term running necessary in field applications.

These limitations clearly define the need for an improved intensifier to meet the increasing demands on dynamic high pressure pumping systems. The development of a rotary high pressure intensifier would eliminate these problems and provide a major technological breakthru. At present IITRI is in the process of developing a rotary system. The developmental system alleviates the aforementioned problems, and as a side bonus provides a reduction in unit size. This type of unit would provide the reliability that is required for Navy applications, and could operate on the surface or the bottom.

An integrated tool package can also be developed utilizing a central power source/intensifier module and cutting heads developed for particular application. Such a system could be used for cutting metal, drilling holes in concrete, submarine pipeline maintenance, etc. As an example of such a systems potential consider submarine pipeline maintenance. A typical pipeline is 31 in. in diameter with a 5 in. concrete/asphalt coating. The time required to remove an 8 ft section of this coating all around this pipe is 16 hrs.[2] (This section length is typical of that necessary for welding two sections together.) Using a water jet system working on a duty cycle (using a 30 HP source) the time would be 3 hrs. If more horsepower is available the time would be further reduced. This savings in time translates directly into increase diver productivity for a given bottom time.

The final consideration concerns the transmission of the high pressure liquid from the source to the cutting nozzle. If a diver portable system is developed this is not a consideration, but the development of such a system, while technically feasible, may not be realistic from a performance and economic viewpoint. For a cutting nozzle remote to the pressure generating source the question is most appropriate. A full line of transmission components (i.e., fittings, tubing, valves, etc.) are available from commercial manufacturers. The high pressure fluid can be transmitted over substantial distances without an appreciable loss in power. The only component lacking is a high pressure swivel. This component is necessary in any articulated system and particularly in a diver controlled device. Prototype units have been built and tested to pressures of 100,000 psi[3] using a controlled leakage type of coupling, but these couplings must be proved in a marine environment.

System safety must also be considered since any leakage can produce a jet with the same destructive power as the cutting nozzle jet. Although this problem should not be overlooked, a crack that is produced generally has an opening area much greater than the nozzle diameter and the pressure drops very rapidly. Though this may be desirable from a personnel safety viewpoint, the resultant unloading of the system can cause severe damage due to excessive system dynamics.

The feasibility (technical) of a high pressure water jet to cut metal in a marine environment has been demonstrated. Although it has been demonstrated the following recommendations are made toward future development.

1) Perform an economic cost/benefit analysis to ascertain the tradeoff between conventional techniques and water jet cutting. (Use the performance data in this report as a preliminary basis.)
2) If the performance of the water jet system is lacking to make it cost effective,

2) continued

determine the required performance and identify/ access areas of possible improvement to the water jet.

3) Identify areas of improvement in intensifier and fluid transmission components technology.

4) Using the technological and economic data as input develop a specification for a prototype marine jet cutting system.

5) Build and field test a prototype system.

The completion of a program encompassing the above sequence will lead to a prototype system able to meet the needs of the Navy, but the program should be undertaken only if the accessment in recommendations 1 thru 3 are realistic.

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